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CAPITAL/LABOR SUBSTITUTION AND FACTOR PRICE RATIOS IN A MILITARY SERVICE: A STUDY OF DEFENSE RESOURCE ALLOCATION

Rolf H. Clark

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CAPITAL/LABOR SUBSTITUTION AND FACTOR PRICE RATIOS IN A MILITARY SERVICE: A STUDY OF DEFENSE RESOURCE ALLOCATION

A Dissertation Presented

By

ROLF H. CLARK

Submitted to the Graduate School of the
University of Massachusetts in partial
fulfillment of the requirements for the degree of

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My postgraduate education was sponsored by the United States Navy. I would like to express my gratitude to that service for the generosity and foresight implicit in its Doctoral Studies Program, which allows several members to gain advanced degrees each year. I hope I can repay my debt through increased productivity during my remaining Navy career.

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Gerald Zeisel inspired effort, respect, and friendship. I hope we shall communicate in the future as we have in the past. Kenin Sahin always saw problems from new and different aspects. His tactic was to lead, rather than push, students through the maze. Fred Kramer provided illumina-

tion in the fog of public budgeting. If it seems unusual that the study of budgeting should be lively and interesting, it is because Fred is an unusual person.

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Finally, this effort could not have been done without the quiet but persuasive presence of my wife Leslie...but then, what effort could?

ABSTRACT

CAPITAL/LABOR SUBSTITUTION AND FACTOR PRICE RATIOS
IN A MILITARY SERVICE: A STUDY OF
DEFENSE RESOURCE ALLOCATION

By Rolf H. Clark, B.S., Yale University
M.S., Naval Post Graduate School
Ph.D., University of Massachusetts

Directed by: Dr. William B. Whiston

While some analysts claim U.S. Defense systems should become more capital intensive to offset rising labor costs, others feel they are already too sophisticated for the Defense labor force. The research has three goals, which help clarify this division. First, capital/labor ratios as indicators of Defense efficiency are oriented within existing capital accumulation theory. Second, models are developed which are consistent with this theory. Third, the parameters of these models are estimated using U.S. Navy budget and asset data. An attempt is then made at synthesizing the two divergent viewpoints in light of the research models and findings.

The theoretical issues discussed include stocks versus flows in capital valuation, the pricing of input factors, the consistency of pricing and capital valuation in Defense, the embodiment of technical change in new systems, the usefulness of marginal utility when output is not measurable,

and the effects of cost estimating errors, especially biases toward undercosting one factor relatively more than the other.

The findings include the following: (1) both Defense capital and manpower costs are underestimated by approximately 30%, thus cost bias may be insignificant. The implications of upsetting this balance through new policies such as a salary pay system are discussed. (2) Shifts toward higher capital intensity are evident in new systems, but because of the low and decreasing ratio of new to total defense hardware, changes in overall capital labor ratios have reacted slowly. Finding (2) is presented by comparing substitution elasticity for new versus total systems, and forms the basis for synthesizing the two views on proper capital accumulation.

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CHAPTER I

INTRODUCTION

I.1 Background: Divergent Viewpoint on Capital/Labor Ratios in Defense

Recent literature has made reference to the tradeoff between aggregate capital and labor as input factors in national defense [6], [10], [18]. The present research will explore the use of capital-to-labor ratios as a means of evaluating internal defense economic policy over time.

Aggregation of factors is common in economics, with efficiency resulting from the equating of marginal revenue and marginal cost--the first order conditions of common optimization problems. This concept cannot be directly transferred to defense resource allocation. One very basic reason is that defense activity lacks a quantitative output measure [18, p. 248]. Therefore marginal productivity, and similar concepts, lose much of their practical meaning.

Yet marginal trade-offs and their relation to efficiency are so well engrained in economic thinking that the concept is difficult to avoid in defense analysis. Sometimes observers imply that shifts toward capital intensity are appropriate, and sometimes the opposite is encouraged.

I.1.1 Some analysts favor greater capital intensity. Cooper and Rolls, in very preliminary but relevant work, imply that a future trend toward capital intensity may be ap-

propriate to match an apparent recent rise in labor costs relative to capital [10]. Other sources have drawn less guarded conclusions. A staff member of the Defense Manpower Commission, a joint Congressional/Executive body conducting a two year study of defense manpower utilization and needs, has recently stated the personal opinion that shifts away from labor intensity in the armed services is an obvious future policy to gain efficiency [59]. In a widely read Brookings Institution publication four prestigious economists draw a questionable conclusion, which they base on rising percentages of manpower per combat unit in the 1964-74 timeframe [17, p. 300]:

> The point here is...to emphasize that at the very time the price of military manpower is rising sharply, it is being used more, rather than less, intensively. Thus the change in the use of defense manpower has reinforced, rather than partly offset, the effect of higher pay on the defense budget.

While the immediate point here is that an aggregate capital/labor ratio is the basis for the implication made, the observed inconsistency is likely to be caused by something other than the <u>use</u> of manpower. One example is that rising costs and budget ceilings caused cutbacks in combat units (e.g. ships and aircraft) which could not be matched, for contractual reasons, with manpower cutbacks. This would cause temporary manpower excesses until new, more capital intensive equipment could replace the weapon stock. Other explanations are also possible, depending on the underlying

circumstances.

I.1.2 Others favor more labor intensity. While the above references indicate that a shift toward capital intensity is appropriate, others seem to argue the opposite. Some naval officers interviewed claim that much of the new equipment arriving in the fleet is too sophisticated for the average operator and/or repairman, and that less complex (and presumably therefore less capital intensive) systems would be more effective overall. Defense analyst Harry Gilman states there is some evidence that "...the Administration and Congress are subject to continuous pressure to develop capital intensive systems," [18, p. 250]. Murray Wiedenbaum, in his recent book The Economics of Peacetime Defense observes that systems become more complex than necessary [57, pp. 57-62]. He shows that high system costs are often due to demands for excessive sophistication of weapon systems by military planners. Critizing unnecessary "gold-plating" of weapon systems, Wiedenbaum summarizes colorfully by quoting Lewis Carroll's Through the Looking Glass. Alice is surprised at the equipment carried by the White Knight:

> "But you've got a beehive...fastened to the saddle... I was wondering what the mouse-trap was for," said Alice. "It isn't very likely there would be any mice on the horse's back."
>
> "Not very likely, perhaps," said the Knight, "but if they do come, I don't choose to have them running all about." "You see," he went on after a pause, "it's well to be provided for everything. That's the reqson the horse has those anklets around his

feet...to guard against the bites of sharks."

I.1.3 Are the viewpoints really divergent?. There is, of course, the possibility that these two viewpoints are not incompatible. Capital intensity, if it comes in the form of automation, can lead to the need for less labor in both quantity and quality. In that case the shift toward capital intensity is accomplished through weapon systems so automated that they can be operated by unskilled labor. However maintaining and repairing such systems is not likely to be achieved by any but very skilled technicians. The automation theory becomes, therefore, less than satisfactory unless one is willing either to assume such maintenance is accomplished outside of the Defense establishment, or that systems are so well designed that maintenance requirements are low. The former assumption begs the issue rather artificially. The latter really leads back to the basic capital/labor tradeoff problem, for such maintenance free systems only occur at higher cost, and diminishing returns will tend to retard movement toward high automation.

The different viewpoints must, it seems, be explained on more basic grounds. Such explanation seems available, and rests on the theory that the two sides are looking at different things when they evaluate the capital intensities of systems, a matter to be returned to very shortly.

I.1.4 The research objectives. But first, the research priorities are becoming reversed, and need to be clarified.

While the present research was inspired by the apparent divergence in opinions on what direction future systems should take, resolving the argument is not the purpose of the research. The purpose of the research is analysis, not arbitration. Having completed the analysis, it will seem appropriate to comment on the arbitration, and that will be offered in the final chapter. For present purposes, we should turn to the more specific goals of the research, of which there are three.

The first is to investigate the validity of using aggregate capital and labor and especially capital-to-labor ratios, as indicators or policy tools for evaluating Defense efficiency. This is the concern of Chapter II, and requires some discussion of numerous issues in economic capital theory. The objective will be to orient the models eventually selected for analyzing capital/labor trends in Defense.

These model descriptions, presented in Chapter III, are the second task of the research. The models will consider two separate issues relating to system acquisition. The first is the effect of errors made in costing capital and labor input factors. The second is the time dependent trend of capital/labor ratios relative to factor price ratios.

The third task of the research is empirical. In Chapter IV available data is analyzed to estimate the principal parameters of Chapter III's models. This analysis is based on the data provided in the Appendix. Since the data includes

only figures on the U.S. Navy, all results can only be directly applied to that service. Finally in Chapter V, the findings are summarized, and their implications discussed in light of some reservations on the validity of the data and assumptions.

I.2 Preview of Results

I.2.1 Cost bias and factor substitution. There are two main findings in Chapter IV. First, cost bias, the proportional undercosting of one input factor relative to another is not significant--planners seem to estimate both capital and labor costs at approximately 70% of their true cost. The implications of policies which may alter this balance in cost bias are discussed in Chapter V.

The second finding is that if one considers new acquisitions, capital/labor ratios have apparently increased at a higher rate than labor/capital cost ratios. In other words, if changes in capital/labor ratios of the weapon stock must be "embodied" in new acquisitions, then planners have indeed been acquiring systems with seemingly high capital intensity. The "embodied" assumption follows if one assumes that systems, once procured, have fixed labor requirements, but that in systems not yet under production capital and labor can still be substituted.

I.2.2 Substitution and the divergent viewpoints again. This second result allows a brief return to the arbitration

matter. If new acquisitions are a very small part of the overall budget, then obviously the weapon stock in aggregate, that is old and new systems combined, will not change rapidly even though price ratios do. The synthesis of the two viewpoints discussed previously can be based on the difference between the response of <u>new</u> systems to factor price changes and the response of the <u>overall</u> systems to these same changes. It may well be the case that those arguing for greater capital intensity are looking at the aggregate whole, while those claiming over-sophistication are looking at the incremental.

These matters can only be discussed realistically after the theory, models, and empiric results, that is the research proper, has been completed. The models of Chapter III and the empirics of Chapter IV will be rather straightforward, once the theoretical arguments of Chapter II are accepted...or at least understood. Some of the theoretical matters discussed in that chapter include: the measurement of capital; the relevance of marginal utility concepts when output is not measureable; the embodiment or disembodiment of technology in capital; the type of technical change.

<u>I.2.3 Some new data contained in the study</u>. Before turning to those issues, some comments on the data appendix seem proper. The appendix contains both raw data and the raw data adjusted to useable forms for the models of Chapter III. There are several data conversions which are believed

unique to this study of defense activity. First, manpower used by the Navy has been adjusted to reflect the manpower required to man systems, rather than the manpower on-hand. This is consistent with the need to investigate the capital/ labor ratios of systems at full performance of the factors. Similarly, Navy weapon systems have been adjusted to reflect only their active portions. Such adjustment becomes very important in the case of Naval ships; for of the total ship value held in the Navy registry, the fraction inaction ("mothballed") varies from 0.20 to 0.64 over a twenty year period. Furthermore, ships make up such a large percentage of total Navy assets that ignoring the active/inactive status is a serious oversight...afterall, inactive ships have no significant manning requirement. A less important but still significant adjustment for aircraft active/inactive status is also made.

A third major adjustment to the data is also related primarily to ships. In order to speak of weapon stock valued in base year terms, the ages of ships contained in that stock must be accounted for. This is particularly true since ship valuation data is available only in acquisition cost terms, and many ships in the data base were acquired long before the 1955 start of the data series.

Various other adjustments to the raw data are included. In these introductory remarks, however, it is inappropriate

to cover more detail. Rather, it seems best to commence the detailed explanation of the research in proper sequence, and we start with the theory.

CHAPTER II

DEFENSE CHARACTERISTICS AND UNDERLYING THEORY

II.1 Directly Related Literature: A Shortage

Outside of the still formative work by Cooper and Rolls [10], there is little significant empirical work investigating the aggregate capital/labor trade off in Defense--that is for the Defense Department overall.[1] This seems surprising in view of the fact that criticisms of, and support for, Defense allocations are so often voiced in aggregate terms as was indicated earlier. Even the Cooper and Rolls approach is not directly relatable to the present research. In their study the cost of capital is based on the interest rate plus imputed depreciation, and capital valuation is based on acquisition cost [10, pp. 16,17]. This would be inconsistent unless capital valued at acquisition cost happened to equal the discounted present value of future output attributed to the capital.[2] Furthermore, the interest rate on funds is

---

[1] There are numerous studies which investigate factor tradeoffs for specific sub-sectors.

[2] The inconsistency is described in general terms in Hick's recent book, Capital and Time [27, Chap. 13]. It must be stressed that Cooper and Rolls work is not yet in final form, and the above is meant to lend comparison rather than voice premature criticism. Furthermore, there are certain equilibrium conditions under which the inconsistency disappears. Section II.5 below explores this matter further.

not relevant unless funds can be borrowed. We shall argue that the Defense Department does not have this option.

The shortage of even unpublished research into aggregate capital/labor tradeoffs in Defense had been confirmed by discussions with representatives at, among other agencies, the Institute for Defense Analysis, the Center for Naval Analysis, the Office of Naval Research, the Brookings Institution, and the Rand Corporation. Dr. Jacob Stockfisch, previously an economist for Defense Secretary McNamara and now with Rand, has stated in a recent conversation that use is often made implicitly of an aggregate defense production function in the conclusions of defense analysts, and that research to investigate the validity of such functions and conclusions was needed [54].

There are three probable reasons for this literature shortage. First, those most familiar with defense problems are concerned with the pressing implementation aspects of defense management, and aggregate considerations seem impractical. Second, economists seem to ignore defense matters.[3] Sumner Rosen, in a scathing critique of present-day economists in general, states:

> We can conclude this survey with the most important abdication of any of the economists. This is a failure which applies across the board: the theoreticians, the

---

[3] A review of the titles of last year's doctoral dissertations listed in the December 1974 American Economic Review indicates one dissertation out of over 800 was directly concerned with defense matters.

> institutionalists and the aggregative economists alike have virtually ignored the most important single force in the American economy of the past twenty-five years, war and preparation for war [43, p. 413].

This academic neglect may be caused by the previously mentioned non-measurability of output. This confounds many economic theories, especially those concerned with optimization.

A third reason for the neglect may be that the talent which has been applied has been aimed largely at systems analysis, operations research, and the like, rather than at broader economic issues.[4] This may have led to suboptimal short term solutions at the cost of long term economy. One advantage of aggregate considerations is that they provide a perspective for viewing these more detailed analyses.

II.2 Indirectly Related Literature: an Abundance

While economic research directly applicable to internal Defense analysis may be less than abundant, it is not the case that economists have failed to provide the basis for such analysis. The classical debates in economics are classical because they are so pervasive. It would be strange indeed if an economic organization as capital-laden as the Defense Department was immune from the continuing arguments

[4] There is a vast literature in these operations research areas. Some widely held texts containing general discussions on Defense are [14], [29], [42].

in capital theory. In the remainder of this chapter the groundwork will be laid for the models presented in Chapter III. This will be based on familiar economic thoughts. While the immediate purpose is to justify the model used herein, the following discussions should help other researchers analyze Defense resource allocations based on variant assumptions--there is no reason the data accumulated in the appendix must be forced into any specific model.

Any model chosen should be consistent with the existing defense institution and its constraints. Collating the available economic models with these constraints is the next task. When completed, there will be some weaknesses remaining--but at least the weaknesses should be explicit, and detailed extensions or modifications should thereby be facilitated.

II.3 Cost Bias and Factor Substitution--Two Separable Problems

There will be two basic models discussed in Chapter III, with related hypotheses tested in Chapter IV. The first concerns cost bias, which is the tendency to undercost one factor of production proportionately more than another. The second concerns the proper substitution of one factor for another (given such substitution is technologically feasible and economically signaled by factor price changes and/or tech-

nical progress).[5] This second issue is normally discussed under the implicit assumption that the factor prices used are the true factor prices. There are reasons why this may not be the case in Defense allocations.

This chapter will concentrate on providing a background discussion. Mathematical presentations of those matters pertaining directly to the research will be reserved for Chapter III.

III.3.1 Factors may be incorrectly costed in Defense--the cost bias problem. First, on the capital side, the Defense Department does not principally buy existing ("off-the-shelf") items. Rather, it contracts for new weapon systems which have yet to be developed. Obviously a contractor estimating the ultimate cost of equipment he has not provided before is less likely to be accurate than if he had already produced the system. Second, such systems are delivered years after the initial contracts are negotiated. This long time span allows further errors between the expected and ultimate costs of hardware systems, even if inflation is abstracted.

On the labor side, military compensation schemes are generally more complex than their corporate counterparts. Instead of wages and salaries (plus certain annuity funds)

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[5]The terms "technical progress" and "technological progress" are used interchangeably in the literature. Here we stay with the term used by Hahn and Matthews in their comprehensive survey of growth theory [20].

accounting for essentially the total cost of labor, the military labor cost is cloaked in housing, medical, and retirement benefits which often are not paid coincident with the labor utilization.[6] A retirement annuity paid by a firm this year for a current worker's ultimate retirement is difficult to ignore as a labor cost. But a retirement check to be delivered by the Defense Department 20 years from now for a current worker is easily ignored.

It is therefore reasonable to expect significant errors in estimating the "price" of labor and capital which will apply when system delivery occurs. Evidence shows such errors tend toward under- rather than over-pricing.[7] It is important to investigate not only the magnitude of such underpricing, but also the tendency to underprice one factor proportionately more than another...which is herein called cost bias.

The costing errors discussed here are those concerned with <u>accounting</u> costs. We are not discussing divergence between accounting and "real" or "opportunity" costs. The latter concept will be discussed further below. For the

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[6]See Binkin [5], for a discussion of military compensation complexity.

[7]Such conclusions are evident in the studies doen at Harvard by Scherer [49, p. 27], by Peck and Scherer [40, Chapter 16], and in the periodic reports to Congress by the General Accounting Office, e.g. [61], [62], [63,], [64].

present, the above arguments should explain the need for what will become the "cost bias" model in Chapter III.

In that chapter it will become evident from the model equations that the cost bias problem is mathematically separable from the more intricate problem of factor substitution over time. This latter problem will be called the "substitution problem," and will be the concern of the second model in Chapter III and the second hypothesis of Chapter IV. The remainder of this chapter will be devoted to trying to sort out the issues involved in modeling this time-phased relationship between labor and capital in the Defense context--conditioned on the assumption that cost bias has been removed.

II.4 The Substitution Problem

The model developed to analyze factor ratios over time will involve such economic issues as fiscal decentralization, the form of capital accumulation, the elasticity of factor substitution, and the type of technical progress. The eventual model will show the Defense Department as an agency controlled by society through decentralization. It will be characterized by "ex-ante substitutability/ex-post fixed proportion" (putty-clay) capital accumulation. Furthermore, changes in factor ratios will be embodied in new acquisitions. These issues will be discussed separately.

<u>II.4.1 DoD and society, a case of decentralization through capital rationing.</u> The research is concerned with the effectiveness of economic decisions <u>within</u> the DoD (Department of Defense). Society's effectiveness in allocating <u>to</u> Dod, as exercised through Congress, is not investigated per se. Confusion results if that distinction is not kept clear. For example, the fact that society determines the compensation to a recruit to be $X per month when the same recruit's opportunity cost (what he could produce elsewhere) is $Y does not mean <u>DoD</u> should use $Y as the cost of a recruit to Dod ... it means <u>society</u> should use $Y in determining the cost of a recruit to society.

In essence, DoD is a decentralized agency. It makes decisions on system acquisitions subject to constraints placed on it by Congress. The constraints take the form of manpower ceilings, appropriations limits, various limitations on weapon types, etc. Given some output measure and objective function, it would be theoretically feasible (and very desirable) to optimize output subject to the imposed constraints.[8] Unfortunately, it is difficult to find objective functions for Defense--even more devastating is the

---

[8]Such an optimization process in a linear form is described in Weingartner's seminal work [56], with further insights added by Baumol and Quandt [3], Carleton [8], and Carleton, Kendall and Tandon [9]. Nonlinear treatments are also possible. See Kirk [34] for a general treatment of optimization.

fact that output is not even measurable, a matter which pervades the analysis and dictates the approach taken.

Continuing with the enumeration of DoD's constraints, it is assumed that DoD budgets, imposed through appropriation authorizations, are fixed in real terms once approved. Furthermore DoD cannot borrow or lend funds on the money market to modify the phasing of these appropriations. Thus, a fairly pure form of "capital rationing" is in effect.[9] "Real terms" are specified because Congress essentially supplements defense appropriations to compensate for unexpected cost increases imposed on DoD--as it did to compensate for the pay increases in 1968. Defense programs suffering due to unexpected general inflation are normally supplemented as well. Of course new obligational authority (NOA) will suffer as a result of these supplemental needs, but that effect is internalized in the proposed models.

II.4.2 The treatment of inflation. Amplification of this treatment of inflation seems appropriate. The central fact is that unlike more autonomous organizations,[10] the de-

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[9]The implications of capital rationing, particularly on the cost of capital as an opportunity cost and therefore on capital valuation is provided in Burton and Damon, who state, "Our main result is a proof that the cost of capital for... [pure capital rationing]...is not well defined and is a meaningless concept." [7, p. 1165]. Capital valuation will be discussed further in Section II.5.

[10]Such organizations can, for example, borrow funds now if they foresee high interest rates. DoD does not have this option.

centralized DoD is not (and perhaps can not be) held responsible for inflationary effects. This results from the capital rationing concept characteristic of decentralized agencies. More specifically, Congress approves the defense budget based on an expected inflation rate. If subsequently an unexpected higher inflation rate occurs, Congress supplements the DoD budget to offset resulting cost increases.[11] The mechanisms for doing this are the supplemental budget requests DoD (and other agencies) submit toward year end.[12]

Since planners should be evaluated based on foreseeable events, and since economy-wide or even world-wide inflation are not matters controllable by DoD, it is important to abstract inflaction from the study. In fact, if DoD foresaw inflation, it could not act to plan for it anyway. This peculiar situation can be emphasized as resulting from the capital rationing environment by considering the negative case: If in 1967,[13] DoD planners requested appropriation

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[11]For example, in FY-1975, the FY-74 supplemental request submitted by DoD included, among other items, a $480 million increase for fuel price increases and a $3.4 Billion dollar increase for increases in pay resulting from legislation. See [71, pp. 16-20].

[12]In the US Budget for FY-75, supplementals are described as representing "...the amounts required for various pay increases...and the additional amounts requested to meet unforeseen program costs, [60, FY75, p. 283].

[13]The 1967 CPI was only 5 points above the 1957 level.

budgets based on a 10% inflation which they thought might occur when systems were delivered in 1974, Congress would undoubtedly have denied the request. Similarly, if today DoD proposed budgets based on what some planners expect to be 17-18% inflation in 1978, Congress (acting on society's behalf) should scale down the request. In essence, the decentralized agency is relieved of the responsibility for planning for unexpected inflation. Society (correctly) reserves that responsibility by determining the inflation rate to be used by DoD planners. That is why in Chapter IV both capital and labor prices are adjusted to abstract unplanned inflation. The aim is to evaluate DoD planning within the constraints imposed, and one of the constraints is that DoD is not accountable for unexpected inflation in the budget process.

II.4.3 Further orientation: defense operates as an open system within society. Society's constraints are the reason why opportunity costs to society and to DoD planners may be related only very indirectly. Properly functioning, DoD responds to the constraints, and society has the task of ensuring the constraints are consistent with society's goals.[14,15]

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[14] The fact that the DoD influences society's views through lobbying-type efforts is ignored. Martin Bailey's claim that the defense establishment resembles a Robinson Crusoe economy is accepted [2, p. 339].

Operating within these constraints DoD presumably procures defense systems consisting of hardware (capital) and manpower (labor). Equipment is purchased from outside the DoD, and manpower is hired to operate the equipment. Equipment once obtained is supported and maintained internally. Consequently labor involved in operating, maintaining and supporting the systems can all be considered collectively as the defense labor requirement. Combined with the total weapon equipment stock, it determines the capital intensity of systems accumulated. The recent concern with the dichotomy between operating and support personnel (in military jargon, the "Teeth-to-Tail" ratio) is not felt to be an important distinction unless it can be shown that one of these personnel components is underutilized. Observations that the support category is growing relatively does not lead to interesting conclusions unless it can be shown that the systems accumulated do not justify such a shift. Martin Binkin's concern that support costs are a large rising proportion of Defense expenditures [4] therefore has no direct impact on the present research, for it may be that such shifts have been efficient.

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[15] Society's allocation problem is covered in great detail and controversy in the large body of literature on social investment. Representative yet different viewpoints regarding the proper social cost of capital for federal expenditures are Arrow [1], Harberger [21], and Haveman [23, App. B].

The sole output of defense is "National Security," which defies measurement and is therefore assumed non-measurable. Nonetheless there is some implicit production function in operation which combines equipment and manpower to produce security. Consequently the concept of marginal utility has meaning, though a specific production function will not be required.[16]

Partly as a result of the decentralization assumption, the economic process of defense expenditure is an "open" system. The cost of capital funds to DoD, for example, is not an endogenous variable,[17] and neither is the cost of labor. DoD is assumed to compete for labor on the open market. Combined, these effects make Dod a price-taker in both capital and labor.

Furthermore, "National Security," the sole output of Defense, is not a product that is re-investable. DoD does not produce systems that can be used to produce other systems. That is not completely accurate, as Naval shipyards, for example, are capable of producing ships. Yet, as pointed out by Wiedenbaum [57, pp. 49,50], the preponderance of Defense systems are produced by private industry. Virtually

[16] Contrasting approaches are offered by Niskanen [39], who offers specific models of bureaucratic output under various types of constraints.

[17] In fact, under pure capital rationing, which is somewhat resembled by the fixed DoD budgets, the cost of capital (in the accounting sense) is zero up to the budget level, and infinite thereafter.

all aircraft, missiles, and electronics are purchased, and Navy shipyards are now largely used for repairing and maintaining, rather than building Navy ships. This lack of reinvestment opportunity means that the model does not require a feedback mechanism. Such feedbacks are at the heart of dynamic analysis such as economic growth theory. The open system here assumed for Defense allows a time dependent, yet static analysis of the relationship observed between capital, labor, and their respective prices.[18] This considerably simplifies the analysis.

II.4.4 Stability is not essential in an open system. Since the research will be concerned with an open system over a limited time span (about 20 years), stability considerations are not vital. Trends showing a capital/labor ratio which rises without signs of abatement are acceptable within the model. Only in the economy as a whole, wherein prices are endogenous (and the system is essentially closed) should stability be a realistic concern--and even then periods much longer than 20 years need to be considered. This again indicates the essentially micro-economic aspect of the approach. Macro-economic models cannot dispense so easily with stability.

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[18] Time variant systems are not necessarily dynamic in the full (feedback) sense of the term. The system to be considered best fits the "static and historical" classification of Samuelson [45, p. 60].

II.5 The Measurement of Capital

There are two basic ways to measure capital. The way most favored by economists is the "value" measure, which values capital at the discounted present value of its future earnings.[19] Accountants, on the other hand, are required to utilize the "volume" measure of capital, wherein capital is measured as the sum total of acquisitions adjusted for depreciation. If this amount is adjusted also for changes in price levels, then the volume of capital can be measured as the replacement cost of the existing physical stock of (depreciated) capital goods. This volume measure provides a proxy for the "real" measure of capital.

<u>II.5.1 Forward versus backward looking capital, problems with each, and a choice</u>. Sir John Hicks, with characteristic insight, refers to the value measure of capital as "forward-looking" capital, and the volume measure as "backward-looking" capital [27, p. 157]. In the present research, the backward-looking measure is used. This is not by choice so much as by default. The forward-looking measure requires knowing the future outputs, yet there <u>is</u> no measurable output. The value measure abandons us.

The only other thing worth mentioning on the forward-looking matter is incidental and regards the choice of input

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[19] This measure is attributable to Irving Fisher [15], and perhaps best illucidated by Hirshleifer [28, Chap. 2].

prices. With no output measure and specifically (therefore) with no objective function, the concept of "opportunity cost" loses meaning. Consider the earlier comments on DoD as a decentralized organization. It is quite valid to speak of the opportunity cost of a recruit to society, for society has quantitative output measures to maximize (GNP, for example). But the opportunity cost of a recruit to DoD is unobtainable since output is not measurable.[20]

While it is true that there is some implicit production function with "National Security" as an output, implicit (that is, unknown) opportunity costs as prices are of no use. The input factor prices used, then, must be associated with the backward-looking capital measure, which is available. The prices selected in the research are the Commerce Department's price indices for capital goods. These are consistent with the capital measure for the purposes required.[21]

There are of course difficulties in using the backward-looking measure of capital too. Most of these can be accounted for given the proper information. One, however, is

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[20] Opportunity costs are descriptively defined as the marginal change in output per unit change in input. With output unmeasurable, opportunity costs are not available.

[21] While price indices are not directly related to the cost of any specific equipment, they do reflect the relative cost of capital when compared with similar price indices for labor. These relative price ratios provide the comparison with the realtive levels of hardware and manpower (capital and labor) analyzed in Chapter III.

quite serious. It is the index number problem which arises when goods obtained in different years are "updated" through the use of price indices to obtain constant dollar valuations for capital in some base year. Informally stated, it is not valid to compare goods A, B, and C with goods B, C, and D through price indices which had to be based on the comparison of the goods in the first place. In the case of capital goods, even though their physical characteristics remain unchanged their productive capacity may not; so even if the same physical goods are compared, the comparison may be invalid.[22] In the present research we could assume that identically physical goods have the same implicit output, and proceed as though the comparison is valid. In fact, we can be less restrictive and only assume technical progress is Hicks neutral. The subsequent model of fixed proportions ex post and substitution ex ante is consistent with this assumption and in fact necessary if any validity is to be

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22More formally, when comparing capital goods in one period with those of another, both the Laspeyre ($L=\Sigma p_0 q_1/\Sigma p_0 q_o$) and the Paasche ($P=\Sigma p_1 q_1/\Sigma p_1 q_0$) indices may be lost. The value index ($V=\Sigma p_1 q_1/\Sigma p_0 q_0$) is of no help without one of the others: $P=V/L$. Hick's discusses these capital measurement problems in his Part III of <u>Capital and Time</u> [27], see especially pages 153-54. He points out, though, on page 154, that those theorists who prefer the value theory have a similar problem, in that final goods (consumables) have value only in their <u>utility</u>, and utility is related to output much as output is related to physical capital. The index number problem therefore remains even in the forward-looking method of capital valuation.

attached to evaluating (backward-looking) capital in constant dollars.[23] Technical progress, its bias, and fixed versus substitutable proportions will be covered further below.

The above comments and the related footnotes indicate the importance of orienting models of capital accumulation within the framework of consistent assumptions. The comments are believed important not only to ensure consistency in the present research, but for understanding and evaluating other models of defense resource allocation. The data available dictates that the present effort utilize backward-looking capital as the measure of capital stock, and that capital cost be directly related to price indices for capital goods. The assumptions required seem less heroic than if the alternate forward-looking technique were used.

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[23]The value theory suffers from another problem associated with footnote 9 above. In order to utilize discounted present value, an interest rate must be known. Yet the interest rate is a price and must therefore be an opportunity cost dependent on the objective function being discounted. This circularity is at the heart of the classic controversies in capital theory. Napoleoni [37] surveys the problem in his first chapter, pointing out the importance of Sraffa's work in reconciling the problem under special assumptions [53]. An analogous problem exists in the microeconomic case of capital rationing treated by Weingartner [56]. See Baumol and Quandt for specific criticisms of Weingartner's use of a predetermined cost of capital [3], and Burton and Damon [7] for recent word on that controversy.

II.6 Fixed Factors and Substitutability

Weapon system procurement is such that hardware and manpower factors are substitutable when a system is planned, but essentially fixed once procured. While some modifications to systems can be accomplished <u>after</u> procurement (e.g. a computer can replace an operator), in the large such modifications are relatively minor--a cargo ship cannot be made into an aircraft. Such "ex-ante substitutability/ex post fixivity" in factors was introduced in Johansen's model [31]. Phelps uses the descriptive and less tongue-twisting term "putty-clay" [41], which will for convenience be used here. Solow's article is more specific on the capital accumulation issues under consideration, and the model in Chapter III is a transmutation of his model in [52].

<u>II.6.1 Putty/Clay modeling</u>. Of interest for present purposes are not the results of Solow's model, but his model set-up, especially his treatment of capital stock, which comes in the form of "machines". Solow defines a machine to be the amount of capital required to produce one unit of output per year. Once produced each machine can only operate with a crew of fixed size (the hard "clay" part). New machines, however, have substitutable factor proportions ("putty") which depend on the relative factor prices and their marginal products. In the present model, since output is not measurable, a machine is instead defined to be

a unit of capital input measured in constant (1967) dollars. As in Solow's model, each old machine requires a crew of fixed size, and new machines have substitutable factors.

The point of this subsection was to state that the putty-clay type model exists and that weapon procurement fits it reasonably well. That has been done, but by going a bit further some insights can be gained which may assist defense planners.

II.6.2 Putty clay and forward/backward looking capital...a synthesis to aid orientation. Risking some repetition, a review of some of the earlier remarks on forward- and backward looking capital, combined with the "putty-clay" model, can put some of the theoretical problems and the selected solution into perspective. Usually, to tie capital, labor, and output together, one defines aggregate capital in terms of the discounted output it produces (the forward-looking "value" theory of capital). Capital then has a unit price closely associated with the real interest rate on funds.[24] Labor cost is also normally measured in output units. The proper capital/labor ratio is then obtained by comparing marginal product ratios with marginal cost ratios.

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[24] Capital in its "value" form is really liquid capital as opposed to physical capital stock. This difference is closely related to the "stocks and flows" definitions of capital equilibrium. See Hicks [26, Chapter VIII], for discussion along this line.

When output is not measurable capital cannot be valued in output units. Thus it cannot be priced directly as a function of the interest rate. "National Security" cannot be converted into terms of capital goods since it cannot be sold or used in production. The proposed alternative was to shift to Hicks' backward-looking capital. Labor input is measured in man-years, and costed in the same dollar units as capital. But now, even with capital and labor inputs known and their relative prices given, there is no tie with output. The marginal factor products are not available if output is not measurable, and factor prices are therefore not relatable to output units. There is no way to apply the standard first order conditions of optimization and the usual economic approach seems to break down.

Mathematically, if w and r are the costs of labor L and capital K, then the first order conditions are (see [24, p. 64]).

$$\frac{\frac{\partial Q}{\partial L}}{\frac{\partial Q}{\partial K}} = \frac{w}{r} ,$$

where $Q = Q(K,L)$ is output. If Q, w, and r are all measured in compatible units, and if $\partial Q/\partial L$ and $\partial Q/\partial K$ are obtainable, then no theoretical difficulties exist. However in the defense context, not only are the two partial derivatives unavailable, but Q comes in the vague form of "National Security," the units of which are not comparable to the units of

w and r.

But the situation is not economically hopeless, although some sacrifice is inevitable as will be seen. The key to salvaging the situation is to abandon the concern with the efficiency of a particular capital/labor allocation and to stress the consistency of the allocation process over time. This is done by comparing changes in capital/labor ratios at different times...or more concretely, by comparing them to some benchmark value such as the ratio which existed at an arbitrary time zero. Then economic behavior which reflects reaction to changing conditions--such as factor prices--can be evaluated as correct if the reaction is consistent, and questioned it if is not. Such before-after comparisons are common as has already been pointed out. What is less common is the realization by analysts that by making such comparisons, they have really assumed two things: (1) the base value (initial conditions), for the comparison is efficient; and (2) conditions have not changed severely during the comparison period. The latter assumption is usually well understood. The former is not. "Consistent" behavior may be very suboptimal if the arbitrary benchmark selected is one wherein the system is far out of equilibrium. Suppose a point is selected where the capital/labor ratio for DoD is not in "steady state" (borrowing that term for expository reasons). This might be the case after a major

policy change in factor pricing, e.g. the recent shift to an all volunteer force. Subsequent evaluations of the movement in the capital/labor ratio will be invalid if steady state was assumed for the benchmark. This does not present a modeling problem, for the system can be modeled without knowing the initial conditions. But an incorrect evaluation results if a correct model is applied with incorrect initial conditions. The practical safeguard is to select the time zero benchmark to coincide with a timeframe such that steady state is likely.

Returning to the main point, it seems, under the putty-clay model, that new acquisitions are based very much on the concepts of marginal utility. Obviously new weapons somehow <u>are</u> selected with knowledge or at least expectations of factor prices. That sounds very much like a "value" approach to accumulation of systems. Yet earlier it was claimed that the model was based on the volume theory, or backward-looking concept of capital. The solution of this apparent inconsistency is explainable--and the explanation may contribute to understanding. The clue lies (as so many clues do) in Hicks' 1973 analysis, though he is discussing a different point at the time. In discussing how to obtain an initial (time zero) measure for capital in the volume sense he suggests an arbitrary time (similar to our "zero benchmark" above) where the value and volume measures can be <u>assumed</u> equal. He states

[27, p. 159]:

> "...it is perfectly consistent to use the value of capital at the base date as the initial volume,..." (underlined word italicised in original).

This can be applied to the putty-clay case as follows. For new acquisitions the "base date" is in fact the time the purchase is made. So while new purchases are based on value arguments, they are simultaneously volume measures. Planners spend $X on a new system because its value is $X, and $X is the volume of the new acquisition since it costs $X. New purchases continue to be volume measures subsequently but cease being value measures since they can not be exchanged for newer equipment reflecting new factor prices (there are few markets for used weapons). Thus it is consistent in the putty-clay model to refer to all capital as being capital volume, or backward-looking. The putty-clay model seems to serve the ancillary purposes of synthesizing the volume and value views of capital. More directly, we can use a model which allows purchasing new defense systems based on marginal utility considerations, yet still measure capital in a backward-looking sense. Finally, this allows using price indices for the price of capital, since price indices are also based on backward-looking valuation.

II.7 Technical Progress and Substitution Elasticity

In Chapter III the change in the factor input ratio

over time is attributed to changes in factor price ratios. One could argue, however, that capital/labor ratios change due to the form of technical progress which occurs, and it just happens that prices are changing simultaneously. This argument gains substance when it is recalled that Defense systems are not selected from available "off-the-shelf" substitutes, but rather are developed to meet system requirements, and such development must take place within the technology available. This section will argue that for the open (microeconomic) system being considered, it does not matter, empirically, whether the changes are attributed to substitution or to bias in technical progress.

II.7.1 Some forms of technical progress and its bias. A brief review of the forms of technical progress is appropriate. Technical progress can be factor neutral or factor biased, embodied or disembodied, and induced or non-induced. There are many other classifications, but these will be the the ones of the main concern.[25]

Progress is "Hicks' neutral" over time if, when the factor input ratio is constant, the ratio of factor marginal

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[25] See Hahn and Matthews [20] for a general view of technical progress in the growth theory literature. Takayama [55] has a recent and somewhat more axiomatic approach for classifying progress.

productivities remains constant.[26] This has the obvious corollary that if factor prices remain constant, and decisions are based on equating marginal cost ratios with marginal product ratios (the neo-classical dictum) then there would be no reason for factor input ratios to change. Any change in capital/labor (K/L) ratios that did occur would be attributable to changes in factor price ratios. That is the basis on which the model in Chapter III and the empirical study in Chapter IV are founded.

However the possibility of bias in technical progress should not be simply assumed away without justification. Labor-saving bias (which is the relevant possibility for the results achieved in Chapter IV) exists in the Hicks sense if, when K/L remains fixed over time, the marginal product of capital increases. The corollary is that if technical progress is labor-saving and the price ratio remains constant, then K/L should increase over time.

Suppose now that, as will be the case in the data found in this study, that the labor/capital price ratio (w/r)

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[26] If K and L are capital and labor inputs and if output $Y=F(K,L,t)$, with t a time index, then Hicks' neutrality requires $Y=A(t)F(K,L)$. Harrod neutrality has $Y=F(K,A(t)L)$, or pure "labor augmentation." Harrod neutrality (and its mirror image Solow neutrality, $Y=F(A(t)K,L)$) are more suitable to macroeconomic growth models, especially those concerned with steady-state conditions. For the present case, Hicks' direct use of marginality concepts is more compatible.

increases over time and the capital/labor ratio (K/L) also increases. Is the rise in K/L due to the rise in w/r (substitution) or due to labor-saving technical progress? The point will be that while that question is of theoretical interest, there can be no resolution of it empirically given the constant rise in w/r which occurs in the data. This will be discussed further in Chapter IV, but the difficulty is obvious: a constantly rising w/r may cause a rising K/L through substitution elasticity, but it is possible the K/L rise would have occurred through technical changes even if prices had not changed. We can as well, and herein do, arbitrarily choose to ascribe the change to substitution elasticity. The empirical impossibility of differentiating substitution from bias in progress is further discussed below.

II.7.2 Induced technical progress versus factor substitution--an empirical difficulty. Actually, for the microeconomic model at hand, speaking in terms of technical progress is too general. More properly the confounding which occurs is between substitution elasticity and *induced* technical progress.[27] In the latter, entrepreneurs who foresee

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[27] Induced progress was originally introduced by, once again, Sir John Hicks [25, pp. 121-137]. It has been developed further by Kennedy [32], and in the ensuing Samuelson/Kennedy discussion, i.e., Samuelson [46], [47], Kennedy [33]. See also Sato [48], and Fellner [13].

labor costs rising relative to capital costs tend to deliberately develop systems which are capital intensive. The distinction between technical progress and substitution in that case seems to boil down to the following: If, when prices change, other goods are available to replace current factors, then substitution is at work; if other goods must first be developed so they can replace current ones, then induced progress is at work. The difference between substitution and biased progress (at least when viewed in the light of a microeconomic problem) obviously begins to blur.

The empirical difficulties of isolating substitution and bias are highlighted by the nicely descriptive title of the paper by Diamond & McFadden, "Identification of the Elasticity of Substitution and the Bias of Technical Change: An Impossibility Theorem" [12]. The identification is not really impossible except under certain conditions, but these conditions happen to accompany the data available in the present research.[28]

II.7.3 Substitution elasticity, and putty/clay again. Having chosen to ascribe changes in factor input ratios to changes in factor price ratios, we will find in Chapter IV

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[28] Sato discusses the fact that the identification is not quite so impossible in [48]. What is required is, as in most statistical problems, enough variance over time to isolate the two effects. In the present study, the cost of labor/cost of capital trends are too consistent to allow such isolation.

that the preferred estimate for the substitution elasticity turns out to be quite high--considerably greater than 1. There are at least two explanations for this. The first is theoretical, and is based on Fellner's first proposition regarding induced innovations [13, p. 306]. Fellner argues that, depending on the length of time between investment decisions and on the expected rate of rise in labor/capital prices, entrepreneurs will choose new investments with higher K/L ratios than seem optimal based on current prices. This follows from the imperfection of not being able to exchange goods freely at every point in time. In view of the long time periods between investment decisions on weapon systems, an apparently high substitution elasticity derived from Defense expenditure data seems proper.

The second reason for a high substitution elasticity returns the discussion to the putty-clay model and to embodied change. Changes in overall capital/labor ratios can only arise due to new acquisitions since old investments have fixed factor inputs and progress is Hicks neutral. If the overall K/L ratio rises to a fraction x between two time points it means that the capital/labor ratio "embodied" in new equipments must be greater than x.[29] If substitution

[29] This also assumes that some old equipment remains, and that equipment retired between the time points was representative, in K/L terms, of the aggregate equipment in stock.

elasticity is evaluated based on new acquisitions relative to price ratios, it must therefore be higher than if evaluated on the total equipment stocks. This will be explored within the context of the data in Chapter IV.

With the discussion of some of the underlying theoretical argument completed, we can turn to the mathematical details of the model.

CHAPTER III

MODEL DEVELOPMENT

Exploring the usefulness of capital/labor ratios as monitors of economic consistency in Defense will require developing two basic models. The first concerns the effect, on any particular ratio, of bias caused by errors made in the pricing of input factors. This will be referred to as "cost bias" and should not be confused with references to bias in technical progress. Cost bias exists if, after price inflation in the factor inputs has been abstracted, one factor is undercosted proportionately more than another.

The second model involves the changes in capital/labor ratios which are attributable to changes in factor price ratios over time. This will be called the "substitution model." The cost bias model is a time-invariant, static look at capital/labor choices. The substitution model allows evaluating multiperiod trends in capital/labor ratios.

Since "capital" and "labor" have such well-engrained connotations in macroeconomic growth theory, these terms will no longer be used for the present essentially microeconomic approach. Instead, the more appropriate terms "hardware" and "manpower" will be used. The term "capital/labor ratio" will be replaced by "hardware/manpower" ratio. The term hardware, in particular, should avoid the tendency to think of the capital component in value, or forward-

looking terms. It stresses instead the volume measure of capital as defense hardware...one of the two factors combining to yield national security.

The models naturally are developed with a decision maker in mind. A word on the decision maker is appropriate. Since the discussion is limited to economic variables such as prices and input ratios, then non-economic considerations, such as political, psychological, or social factors, are abstracted. This is equivalent to assuming decision makers act solely on the economic facts at their disposal. These "näive decision makers" do not make mental adjustments to the data they perceive. For example, they would not mentally adjust cost data upward simply because they feel past studies have underestimated costs. This is not completely realistic, however internalizing the psychological aspects which affect real world decisions is beyond the scope of this study.

III.1 The Cost Bias Model

<u>III.1.1 Cost bias defined</u>. Assume that equipment is accumulated through annual purchase decisions made by planners. The planners use unit input prices w_p and r_p for the two system inputs, manpower and hardware. The prices w_p and r_p do not represent input prices in effect when a decision to buy is made. Rather they represent, at the time of the buy decision, planners' estimates of what input prices <u>will</u>

be when the system is delivered.[30] If the actual prices of these inputs at delivery time are ultimately w_u and r_u, then cost bias as used herein is specified by the parameter b, defined

$$b = \frac{(w_p/w_u)}{(r_p/r_u)} \quad . \tag{1}$$

This represents the proportional undercosting of manpower relative to hardware by planners. The difference between prices subscripted by p and those subscripted by u occur because of costing errors resulting from either ignoring system costs which should be included, or from estimation errors which are unavoidable due to the long lead times between the decision to buy and the delivery date of a system.

Rearranging equation (1),

$$b = \frac{(w_p/r_p)}{(w_u/r_u)}$$

For notational conveniences, denote this as

$$b = \frac{(w/r)_p}{(w/r)_u} \quad . \tag{2}$$

III.1.2 Cost bias and marginality considerations. Now consider the well known two-factor graphics of budget constraints and isoquants shown in Figures 1 and 2. Let

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[30] For example, in 1970 planners may estimate labor prices to be w_p in 1975, but when 1975 arrives, labor actually costs w_u.

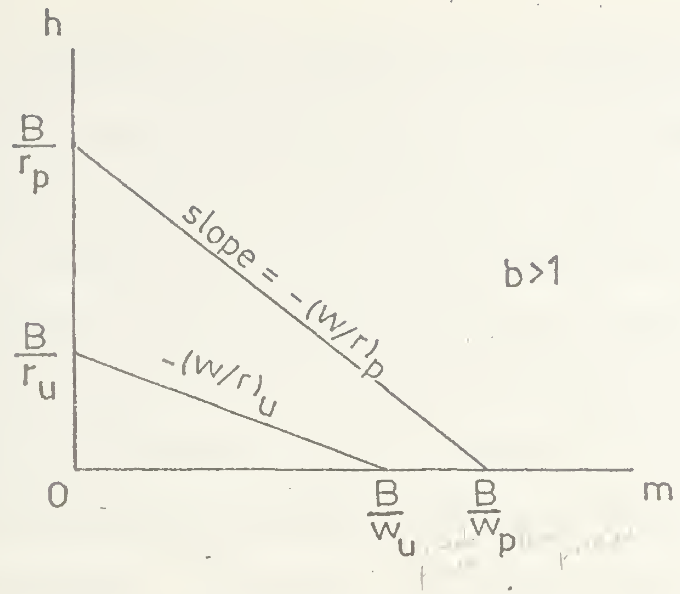

Figure 1. Two-factor budget constraints

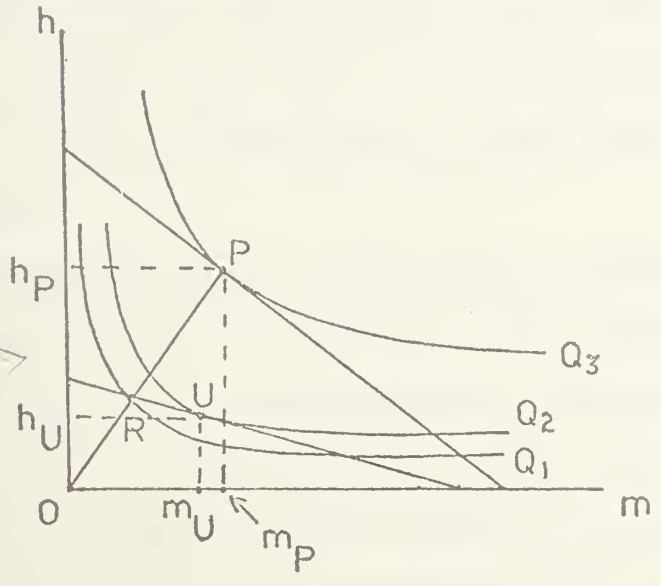

Figure 2. Two-factor isoquants and optima

h_p and m_p represent the hardware and manpower amounts associated with the purchase decisions of a single arbitrary period when prices p are in effect. h_u and m_u are defined similarly. Since $-(w/r)_p$ is the slope of the budget constraint (Figure 1) associated with the hardware and manpower inputs h and m priced at p, and similarly for $-(w/r)_u$, then the cost bias parameter b is a measure of the relative slopes of the planning price constraint and the ultimate price constraint. If $(w/r)_p$ is steeper than $(w/r)_u$ as shown then $b>1$. Otherwise $b\leq1$. If $b=1$, then no cost bias exists.

B is the fixed budget. For Defense, B is analogous to the annual budget approved by Congress. The intercept points result if the total budget B is spent on only the one input: thus B/r_p is the amount of hardware which B will buy at the planning price r_p, when all of B is spent on hardware.

If planning prices p are used by planners, then in Figure 2 systems will be selected with hardware/manpower ratio (h_p/m_p), for it is assumed the planners select systems such that the rate of technical substitution, (RTS)--represented by the slope of the isoquants Q_i--equals the planned factor price ratio $(w/r)_p$. Specifically, $RTS_p = (w/r)_p$; where RTS_p is the slope at P of the highest achievable isoquant Q_3. Summarizing, point P is the selection, at planning prices, of systems which seem optimal. This optimum

calls for Q_3 units of output. These are produced by systems with manpower inputs m_P and hardware input h_P.

In equating RTS to w/r, planners exercise the ex ante substitutability of factors which accompanies new investments. However once the new procurement contracts are let, these systems are assumed to have fixed factor proportions. This means that with a fixed budget, and with actual ultimate prices w_u and r_u, the only way to meet the budget B is to reduce output, or equivalently, reduce the number of systems obtained. Since isoquants represent output units, the budget constraint can only be met by producing Q_1 units instead of Q_3, that is by attaining point R.[31] This cutback in production means a cutback in systems from planning levels P to ultimate levels at R. Such cutbacks are not uncommon in weapon procurement, as can be seen from Table 3, columns (2) and (5).

If the production function yielding the Q_i's is homogeneous, as is assumed here, then at R the slope of isoquant Q_1 equals the slope of Q_3 at P.[32] Therefore

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[31]For the present it is assumed that system cutbacks required in meeting the constraint at R instead of P are made without having an excess in one factor. That is the cutbacks occur along OP. This is the most efficient cutback possible given the ex-post fixed factor assumption.

[32]The homogeneity assumption prevents theoretical difficulties, but is not critical conceptually.

$$RTS_R = RTS_P = (w/r)_p = b(w/r)_u, \tag{3}$$

the last equality coming from (2).

III.1.3 Cost bias, marginality, and substitution elasticity. Point U in Figure 2 represents the solution which would have evolved had planners used the prices w_u and r_u. U would yield the hardware/manpower ratio (h_U/m_U), here denoted $(h/m)_U$. The ratio of $(h/m)_U$ relative to $(h/m)_R$ is needed. Obviously this ratio will depend on the substitutability between hardware and manpower inherent in the production function. Hicks' elasticity of substitution measures such substitutability. Let λ denote this elasticity. Then λ is defined [24, p. 62]

$$\lambda = \frac{d(h/m)/(h/m)}{d(RTS)/(RTS)} \tag{4}$$

III.1.4 The basic cost bias relationship. Solving this expression leads to[33]

$$(h/m) = A(RTS)^{\lambda} . \tag{5}$$

Since A is constant, the following results

$$\frac{(h/m)_R}{(h/m)_U} = \left[\frac{(RTS_R)}{(RTS_U)}\right]^{\lambda} \tag{6}$$

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[33]Use di/i=d(ln i), multiply by the denominator in (4), integrate, and purge of logarithms. A is a constant of integration which will be invariant if λ is constant, which is so assumed. CES production functions, for example, fit this case. See Henderson and Quandt [24] especially pages 85-86.

By inspection of Figure 2, $RTS_U = (w/r)_u$. This, plus (3) leads directly to the relation between $(h/m)_R$, the hardware/manpower ratio resulting from the use of planning prices p, and $(h/m)_U$, the ratio which should have evolved from actual prices w_u and r_u:

$$\frac{(h/m)_R}{(h/m)_U} = b^{\lambda} \tag{7}$$

Equation (7) is the basic cost bias model and shows the effect of cost bias on hardware/manpower ratios, as well as the dependence on substitution elasticity. Equation (7) also shows one reason that the major empirical tasks of the research are to estimate b and λ.[34] With them, the utilization of hardware/manpower ratios as indicators of defense allocation effectiveness may be meaningful, not only for the one period static case above, but for the multiperiod considerations discussed in the next subsection.

III.1.5 Some miscellaneous comments on cost bias. Note the implications of cost bias as specified in (7). If b=1, then the hardware/manpower ratio planned on planning prices p and the one which is efficient based on ultimate

[34] Substitution elasticity λ as used above and the substitution elasticity to be used in the next section are conceptually different. The former is the elasticity due to existing alternatives at a point in time, the latter the elasticity due to alternatives becoming available over time. However since no empirical estimate can be made of the former, it is assumed equal to the latter, which is estimated in Chapter IV.

prices u will be equal. This means that if the prices on input factors are underestimated by the same proportion, the proper hardware/manpower ratio will accompany planned systems. This in turn means that the proper quantity of

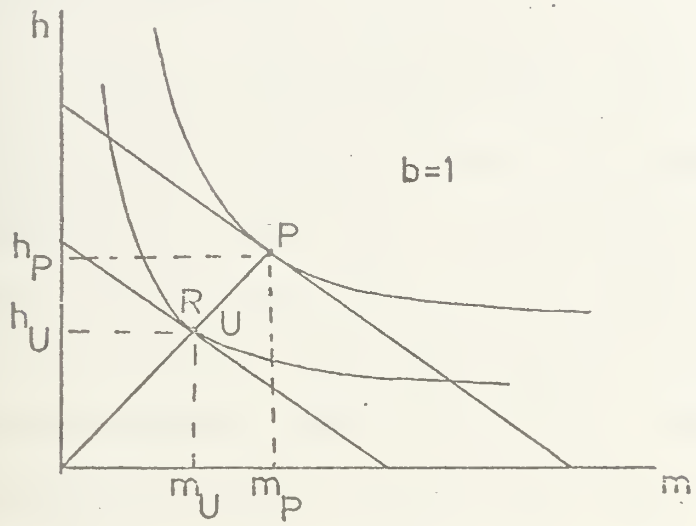

Figure 3. Zero cost bias optimization

systems will be obtained: the fixed budget constraint will force less system units to be obtained than are planned, but this number will match what would have been planned had proper prices been used. This is less confusing in Figure 3, which shows zero cost bias (i.e., b=1) as the budget constraints are parallel. Points R and U coincide, so $(h/m)_U = (h/m)_P$. Even though the wrong prices (p) were used in planning, the same system configuration and quantity results as if the correct prices (u) had been used.

If cost bias is zero, then the implications of correcting the price estimation for only <u>one</u> factor and not the

other are obvious: cost bias will result where it was absent before, and a less satisfactory result occurs than if no such correction occurred. This matter will be further discussed in Chapter V.

III.2 The Substitution Model

Substitution between hardware and manpower is of interest independent of cost bias. In fact the empirical findings will indicate cost bias is not significant. Consequently it is of more practical interest to study the shifts in hardware/manpower ratios over time. These shifts and their relation to factor price ratios lead to the substitution model.

III.2.1 Underlying considerations. Denote the accumulated hardware stock at time t as H_T, and the gross new hardware goods added to the stock between t and t+1 (designated period t) as h_t. Also assume the goods in h_t are homogeneous and their associated manpower requirements m_t are independent of existing systems.[35] If the prices in effect when selecting the goods h_t are w_t and r_t,[36] then $(w/r)_t$ will

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[35]Note the new hardware can be selected dependent on existing hardware, and still have the manpower requirements of the new hardware independent of the old hardware. Thus, a new missile system may be selected dependent on existing guns, aircraft, radars, etc., but the manpower intensity of the new system will probably not depend on the manpower intensities of the existing systems.

[36]Differences between planning and ultimate prices can be held separate from the present considerations since the effect of that difference can be recovered through using (7).

determine the economically correct hardware/manpower ratio (h_t/m_t) inherent in the new goods h_t.[37] Denote this ratio by $(h/m)_t$. Then $(h/m)_t$ is the "full performance"[38] hardware/manpower ratio of the newly acquired, or period t systems...meaning the ratio such that in the new systems (made up of h_t and m_t) both factors are fully utilized. Let $(H/M)_t$ be a similar full performance hardware/manpower ratio associated with H_t. Finally let K_t be the hardware retired from stock through either tactical or physical depreciation in period t and let its associated full performance hardware/manpower ratio be c_t. Now the hardware stock at t+1 must equal the stock at t plus hardware added during period t minus hardware retired during t. That is,

$$H_{t+1} = H_t + h_t - k_t \ . \tag{8}$$

Therefore if the manpower intensity associated with h_t and k_t were known,[39] then the overall hardware/manpower ratio at

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[37] The notation could be simplified by denoting the manpower intensity of hardware by a single parameter, say h' instead of h/m. This is essentially what Solow does in his vintage approach [52]. The notation h/m (and later H/M) is retained to avoid remembering too many definitions in the reading.

[38] The term is used by Hicks [27, p. 52]. It differs from "full-employment" in an essential way. Full employment has a macroeconomic connotation in which prices are endogenous. Here, prices are exogenous, analogous to Hicks "fixprice" model. The term full-performance is more appropriate to a microeconomic model.

[39] "Manpower intensity" being measured by the full performance hardware/manpower ratio inherent in these hardware quantities.

time t+1, could be obtained by using a weighted average of the hardware intensities of the quantities on the right hand side of (8):

$$(H/M)_{t+1} = \frac{H_t(H/M)_t + h_t(h/m)_t - k_t c_t}{H_t + h_t - K_t} \tag{9}$$

This iterative relationship for H/M will yield an absolute value for $(H/M)_t$ if some initial time zero value $(H/M)_0$ is known. To predict what values $(H/M)_t$ should take, this time zero value should be such that the system is in equilibrium, or "steady state" at that time.

III.2.2 Hardware retirement. In practice, even if $(H/M)_0$ is known, $(h/m)_t$ and c_t are not. Hardware is not homogeneous as was assumed, and it would be impossible to record the manpower requirements of each individual item entering and leaving the hardware stock. Even if $(h/m)_t$ could be estimated based on the one period conditions described in Figure 2, (which would require knowing the production function), there is no practical way of estimating c_t. As with most impasses, an assumption is needed.

One obvious assumption is to conclude that the oldest hardware will be retired first, and c_t determined according to the prices in effect when that hardware was originally delivered. Another is to assume the economic conclusion that hardware is selectively retired so as to bring the overall hardware/labor ratio into line with current prices.

This last assumption is unrealistically optimistic, but could prove useful in later research as a "most optimum" baseline case. Unfortunately the first assumption, according to DoD personnel, is also not realistic. Apparently a more random process characterizes the phasing out of old equipment. Systems with strong advocates remain in service, those without do not. Furthermore tactical obsolescence sometimes forces retirement independently of age.

Under such circumstances it is not unreasonable to assume that systems being retired are randomly selected and therefore have a manpower intensity which is representative of the overall average of systems on hand. This makes c_t equal to $(H/M)_t$, a relationship inherent in the use of a net depreciation rate which acts uniformly over the hardware stock (the descriptive term for such depreciation is "evaporative decay," see Karl Shell [50, p. 1]).[40] A fine point, but one worth mentioning, is that depreciation does not act on systems acquired in period t until time t+1.

III.2.3 The basic substitution model. The relationship between $(H/M)_{t+1}$ and $(H/M)_t$ is

$$(H/M)_{t+1} = \frac{(H/M)_t [H_t(1-\delta)+R_t]+(h/m)_t h_t}{H_t(1-\delta)+R_t+h_t} \tag{10}$$

---

[40] Of course, as hardware "evaporates" through exponential decay, the manpower used to man it becomes available for use in newer systems.

where R_t are repair funds for period t, and δ is the (constant) annual rate of depreciation, including both physical and tactical decay. Expression (10) assumes repair funds R_t are used to maintain hardware remaining in the stock at time t...i.e., R_t acts to offset depreciation in hardware. While normally R_t is less than depreciation $H_t \cdot \delta$, it is possible for R_t to exceed $H_t \cdot \delta$. This would imply that repair funds are actually being used to increase, rather than simply maintain, the hardware stock. This allows for the repair funds to be used for procurement purposes.[41]

The derivation of (10) is intuitive. The denominator is total hardware stock held at time t+1, and the bracketed term in the numerator is hardware carried forward from t to t+1. Then (10) simply combines the old hardware/manpower ratio $(H/M)_t$ with the new $(h/m)_t$, each weighted by the relative size of the systems they represent: $(H/M)_t$ representing the remaining old systems, and $(h/m)_t$ the (gross) new systems.[42]

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[41] A phenomenon probably realistic in the "real world" of Defense budgeting. O & M funds could be used, for example, to pay transportation costs actually associated with new procurement. But such flexibility is quite limited overall.

[42] Various modifications to (10) could be considered. These include allowing δ to vary with time, R_t to be phased out over several periods, and letting h_t to be partly made up of hardware planned for delivery at some other time but arriving during t. Such complications would not add significantly to the research, for their effects are secondary.

III.3 Cost Bias and Substitution: Model Synthesis

Equation (6) was derived for the static one-period model on cost bias. An analogous relation can be derived between the hardware/manpower ratios associated with price ratios of two different time periods. At some arbitrary time zero let h/m be $(h/m)_0$ and w/r be $(w/r)_0$. Retaining the assumption of homogenity in the implicit production function, and further assuming the production function reflects Hicks' neutrality, the following results:[43]

$$(h/m)_t = \left[\frac{(w/r)_t}{(w/r)_0}\right]^{\lambda} \cdot (h/m)_0 . \qquad (11)$$

If time 0 is selected to be a time when the initial conditions are known, then $(h/m)_0$ will be known or estimated and (11) will lead to subsequent values of $(h/m)_t$.[44] These

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[43]This results from the definition of λ, the elasticity of substitution, exactly analogous to the derivation of (5) above:

$$\lambda = \frac{d(h/m)/(h/m)}{d(RTS)/(RTS)} ,$$

and the neoclassical assumption that an optimum is chosen at RTS=w/r, lead to $(h/m)_t = D(w/r)_t^{\lambda}$ where D is a constant of integration which is invariant if Hicks neutrality holds and λ is constant. See footnote (33) above. Hicks neutrality ensures that λ isconstant over time for a given h/m ratio.

[44]Initial conditions can take various forms. For example if the w/r trend has been constant and $(H/M)_0$ is known then $(h/m)_0$ may equal $(H/M)_0$ times some constant greater than unity.

values are what are needed to utilize equation (10) and find the (H/M) values over time which would be consistent with the assumptions and with economic efficiency. (H/M) derived in this way would be compared with actual H/M values, that is with ratios of actual hardware to actual manpower, to see if the two matched. From a predictive point of view, policy changes which affected the w/r ratio (such as the 1971 switch to an all volunteer force, which raised (w/r)) could be analyzed to predict the effects on hardware versus manpower trends.

This is all dependent on the assumption that technical progress is (Hicks') neutral.[45] If some known bias exists in progress, then (11) would have to be modified to include the bias factor.

Even under neutral technical progress, the above requires knowing the parameter λ, a quantity which has not been directly estimated for Defense resource utilization. It is for this reason that the research abstains from the predictive approach, and instead concentrates in Chapter IV on the empirical estimation of λ.

The effect of cost bias can be included with the effect of rising (w/r) ratios over time. The latter are specified in equation (11) above, which shows that given an $(h/m)_0$ and the change in w/r between time 0 and t, one can find the ex-

[45]This issue was discussed in section II.7.1 above.

pected h/m for time t. If cost bias exists, and if it is assumed constant through time, then both $(h/m)_t$ and $(h/m)_0$ will be affected identically, that is through relationship (7) above. From (7), if $(h/m)_0$ should have been $(h/m)_0/b^\lambda$ and $(h/m)_t$ should have been $(h/m)_t/b^\lambda$, then no change in (11) would result. It would simply be the case that both $(h/m)_0$ and $(h/m)_t$ were in error by the same proportion, leaving their relative change over time the same as indicated by (11).

Of course, if at time t cost bias is b_t and at time 0 it is $b_0 \neq b_t$, then (11) would become

$$\frac{(h/m)_t/b_t^\lambda}{(h/m)_0/b^\lambda} = \left[\frac{(w/r)_t}{(w/r)_0}\right]^\lambda \tag{12}$$

or

$$\frac{(h/m)_t}{(h/m)_0} = \left[\frac{b_t}{b_0} \cdot \frac{(w/r)_t}{(w/r)_0}\right]^\lambda . \tag{13}$$

The possibility of a change in cost bias is not investigated here, and instead an estimate for a constant bias factor is derived.[46]

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[46]There is at least circumstantial evidence that cost bias may have been constant. First, there has been no major changes in the compensation type pay system which would severely effect manpower undercosting. Second, on the hardware side, Ronald Fox implies there has been little change in system acquisition problems, at least since 1962. Chapter I of his recent book covers these matters. He refers to a well known Harvard study to make his point: "More than a decade

We now turn to that derivation as well as the derivation for λ.

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46 (Continued)
after the publication of The Weapon Acquisition Process, the problems cited by Peck and Scherer are still with us." [16, p. 10]. The Peck and Scherer study referred to is [40]. Even earlier evidence indicating similar cost growth problems is contained in Marshall and Meckling [36]. The general impression one gets is that weapon procurement costs have been understated historically, and that the problem still exists without much change.

CHAPTER IV

EMPIRICS

Two hypotheses are investigated through analysis of data on U.S. Navy resource allocations from 1955 to 1974. The hypotheses are the following:

Hypothesis 1. Costing bias has favored the acquisition of labor intensive systems.

Hypothesis 2. The elasticity of substitution between labor and capital is zero.

IV.1 Investigation of Hypothesis 1

IV.1.1 Manpower undercosting, empirical findings. The results relating to hypothesis 1 are based on weapon system cost studies conducted during the 1960's. The manpower undercosting factor is estimated by comparing manpower costs used in those studies with current figures for total costs of manpower. All costs are normalized to 1974 dollars, using the wage indices shown in Table 9 (column (1)) of the appendix. 1974 estimates for total manpower costs are used because recent emphasis in the costing area has provided comprehensive figures not considered available when the studies were conducted.

Table 1 shows the manpower costs by system. The "cost in current dollars" figures represent the planner's esti-

TABLE 1 -- Manpower Costs Used in Selected System Cost Studies During 1960-70 Period (Costs in Dollars per Man-Year).

System	Current $ Cost		Planning Year	Cost in 1974 Dollars	
	Officer (1)	Enlist. (2)		Officer (3)	Enlisted (4)
ULMS	7,130	4,379	1964	13,475	8,276
B-58	12,535	6,060	1964	23,691	11,453
Seahawk	15,500	4,657	1964	29,295	8,802
PTF	-	5,994	1964	-	11,329
PGH	-	6,192	1964	-	11,703
LAAV	12,000	6,200	1966	20,760	10,726
MFE	16,000	10,000	1967	25,560	16,600
	Average Cost Used			22,556	11,270
	Total Cost			35,320	15,500

SOURCES: Officer and Enlisted costs are obtained from references [80],]81], [83], [84], [85], and [87]. Costs in current dollars are those specified in cost studies, and reflect costs anticipated to be in effect when system is active. Total cost figures are based on [78, App. A and B] with 0-4 representing average officer total and a weighted average representing the enlisted figure. (The weighting by manpower levels in each enlisted grade places the mean grade 1/3 of the way from E-4 to E-5).

mates of what manpower would cost when the systems were activated (see footnote 30). The average values $22,556 for officers and $11,270 for enlisted can be compared with the total cost figures $35,320 and $15,500 respectively. These last two figures are the total costs in 1974 terms of comparable officer and enlisted personnel. Officers were apparently costed at an estimated 22,556/35,320 or 0.64 or total cost, and enlisted at 11,270/15,500 or 0.73 of total cost.[47] Since enlisted pay budgets are approximately 4 times officer budgets, a weighted average for manpower undercosting is 0.71. In the notation of the previous chapter, w_p/w_u equals 0.71.

A problem encountered in the data search yielding Table 1 was that cost studies for systems procured in the 1960s were either not conducted, not available, or, as in most cases, did not explicitly mention personnel costs. The shortage of such studies influenced the decision to include one non-Navy system (B-58). The seven studies included in the analysis resulted from a search of more than 50 studies purporting to be cost studies conducted for the Defense Department during the time frame of interest.

[47]These figures are for "standard" personnel types, i.e., do not reflect the costs of pilots (aviators) submariners, or other specially trained personnel. The ratios obtained would be approximately the same if such personnel were included, as their effects would raise both numerator and denominator of the fractions almost proportionately.

IV.1.1.1 Manpower undercosting, some deducted confirmation of empirical findings. Some confirmation of the manpower undercosting factor obtained can be found in the formal costing instructions in effect at the time. These instructions usually specify that direct costs be used in comparing systems.[48] Discussions with personnel engaged in manpower costing indicate general agreement on the exclusion of such indirect costs as housing, medical, administrative, and retirement benefits from system costing since these are not paid from the "military personnel" budget category. An estimated cost of such items from a recent source shows they are about $11,100 for officers and $4,247 for enlisted.[49] This leads to an imputed undercosting factor of ($35,320-$11,100)/$35,320), or 0.69 for officers and similarly 0.73 for enlisted. The weighted average of these imputs an undercosting factor of 0.72 to manpower costing. The similarity of this figure and the empirically derived

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[48] For example, [70, enclosure 2, p. 5] states personnel costs are charged according to "the cost of military personnel services involved directly in the work performed." The instruction is entitled "Economic Analysis and Program Evaluation for Resource Management," and is a prime directive for guidance in Defense investment analysis.

[49] Reference [72] provides annual composite cost figures for various grades. These do not include the factors for quarters, retirement, variable support, and other support (estimated at 20% elsewhere in the report). The data on page 17 of [72] were used to obtain the above values, which are the ratios of the composite cost to the composite plus the above mentioned exclusions.

0.71 lends at least some support to the conclusion that this last figure is of the proper magnitude.

IV.1.2 Hardware undercosting. The undercosting factor for hardware, r_p/r_u, is obtained from data included in the quarterly "Selected Acquisition Reports," (SARs), required on major weapon systems. Every system under the SAR process is reviewed quarterly to monitor cost changes. Systems included in the present analysis are all Navy systems under procurement as of October 1974. Systems under development, but not yet under procurement, were excluded because the cost data associated with such systems are preliminary and therefore less accurate. Furthermore, initial cost estimates are those specified in the SARs to be "development estimates." The earlier (and usually lower) "planning estimates" are not used since major funds are not obligated until the development phase begins. This commitment tends to make the cost estimate more accurate.[50]

IV.1.2.1 Hardware undercosting as evidenced by SAR cost growth categories. The hardware undercosting factor is derived by comparing each system's unit cost as estimated at the development date with the unit cost as of the

[50] These opinions result from discussions with personnel at the Office of the Assistant Secretary of Defense (Program Analysis and Evaluation). They are explicitly stated in [76].

October 1974 SAR. Each SAR specifies the components of cost change, the major categories being: economic (inflation), quantity, engineering schedule, support, and estimating changes.

The types of cost changes included in each category are the following:[51]

> Economic: Cost increases caused by contract changes resulting from revised economic forecasts. These are essentially inflation caused.
>
> Quantity: Cost changes caused by changes in the number of units of a weapon type being produced.
>
> Engineering: Cost changes caused by altering the physical characteristics of a system in procurement or development.
>
> Schedule: Cost changes caused by adjustments in the delivery schedule or other milestones in the production schedule.
>
> Support: Cost changes caused by changes to support equipment or services indirectly linked to the major system considered. An example would be a change in the specified number of spare parts per unit.
>
> Estimating: Cost changes due to corrections or refinements of previous estimates.

These changes have obvious overlap areas, and costs belonging to one category may be erroneously or even deliberately ascribed to another. A contractor could, for example, blame inflation for inefficiencies in scheduling, and perhaps escape detection. However there are government safeguards against such actions. Whatever, the SAR's do expli-

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[51] These categories are discussed with examples in [62, pp. 40-44], and in Fox [16, pp. 365-368].

citly place cost growth into the various categories, and this study can only assume these placements are approximately accurate.[52] Further discussion on this matter is contained in section IV.1.2.4.

Of these different cost growth categories, economic and engineering changes are abstracted from the cost growth figure obtained in this analysis. The first because inflation must be excluded from the hardware cost growth considerations as it was from the manpower side. The second because engineering changes presumably cause system improvements, and unit costs should be adjusted to compensate. <u>All other cost categories are assumed to reflect improper cost estimation at program inception</u>, and to therefore be properly included as factors in cost growth. Table 2 provides the various systems considered, the changes in estimated unit costs since program inception, and the program weights w_i which reflect relative program size in dollars of budget commitment. Obviously any estimate of cost growth which is based on the individual cost growth facts of the separate programs must take the relative size of the program into account. Table 2 is derived from Table 3 which contains the raw data directly from the SARs.

A comparison of cost growth relative to time since pro-

[52]For a discussion of contract changes, their causes and implementation, again see Fox [16, Chapter XIX].

TABLE 2 -- Cost Growth Data for Navy Systems Under SAR Process

System	System Weight (w) (N)	Program Length (yrs.) (2)	Years Since Program Initiation (t) (3)	Growth Factor (g) (4)
A-7E	4	11	6	1.19
AIM7F	1	--	6	1.76
CONDOR	1	12	7	3.86
DVAN 6819	6	13	7	1.04
DD 963	7	8	4	1.14
DLGN 38	2	7	5	0.96
E-2C	2	8	3	1.23
F-14	17	8	5	1.39
LHA	4	9	5	1.39
MK 48	5	10	5	1.17
P-3C	4	13	7	0.83
PF	9	11	2	1.01
PHM	2	9	1	1.10
PHOENIX	1	16	11	1.57
POSEIDON	13	12	8	1.01
S-3A	8	7	5	1.03
SSN 688	16	8	3	1.00
VAST	1	--	6	2.05

NOTES: Column (1) is relative program size, based on data in column (1), Table 3. Column (2) is estimated from available information. Column (3) is time, to nearest year from program development date to October 1974. Column (4) is obtained by dividing column (6) of Table 3 by sum of columns (3) and (9) of that table. "g" is the multiplier indicating per unit cost growth unexplained by inflation and/or engineering modifications since program development date.

TABLE 3 -- Cost Data for Navy Systems Under SAR Process, Under Procurement, as of October 1974 (Dollar Figures in Millions).

	Development Data			Current Data			Explained Cost Changes		
System Designation	Total Cost (1)	Units (2)	Unic Cost (3)	Total Cost (4)	Units (5)	Unit Cost (6)	Inflation (7)	Engineering (8)	Unit Change** (9)
A-7F	1,466	595	2.46	2,590	646	4.01	365.0	203.0	0.92
AIM7F	454	10,785	0.0421	800	6,804	0.118	212.0	6.8	0.025
CONDOR	441	3,348	0.132	412	538	0.766	38.7	90.0	0.066
CVAN 6819	2,036	3	679.0	2,558	3	853.0	336.5	92.3	143.0
DD 963	2,581	30	86.0	3,599	30	120.0	574.0	0.0	19.1
DLGN 38	820	3	273.4	1,593	5	318.7	222.5	12.3	58.7
E-2C	586	30	19.4	985	36	27.36	46.4	49.2	2.9
F-14	6,166	469	13.15	6,307	334	18.88	194.0	-2.2	0.478
LHA	1,380	9	153.0	1,180	5	236.0	110.4	1.9	16.2
MK 48	1,754	*	*	1,557	*	*	124.3	9.4	*
P-3C	1,294	104	12.44	2,719	214	12.71	296.0	135.0	2.79
PF	3,244	50	64.88	5,275	50	105.5	1843.0	111.3	39.1
PHM	726	30	24.2	1,108	30	36.9	250.0	28.0	9.27
PHOENIX	536	2,384	0.225	1,160	2,532	0.458	163.0	0.0	0.066
POSEIDON	4,569	*	*	4,811	*	*	0.0	196.0	*
5-3A	2,891	199	14.53	3,289	187	17.59	481.0	0.0	2.49
SSN 688	5,748	*	*	7,863	*	*	1309.0	5.2	*
VAST	312	207	1.51	449	89	5.04	46.7	94.4	0.95

SOURCE: Department of Defense, Navy Department, Selected Acquisition Reports for October 1974 (Unclassified Budget portions).

NOTES: * Classified data element
** Columns (7) + (8) divided by 1/2((2)+(5))

gram inception confirms the widely held view that weapon system costs are underestimated. Figure 4, a plot of the Table 2 data, is descriptive, indicating a positive correlation between cost growth g and time t (columns (4) and (3) of Table 2).

This relationship can yield a hardware undercosting factor comparable to the manpower undercosting factor w_p/w_u. Statistical tests to yield confidence intervals on the undercosting factor will not be valid for reasons to be discussed in the next paragraph. Consequently an "average" value for r_p/r_u must suffice. The estimate is obtained by first deriving a (modified) least squares fit between the weighted program cost growth factors g and the time since program inception t, with cost growth required to be zero at program inception. The mean program length (column (2) of Table 2) is then used to choose a point yielding the estimate for average cost growth per unit. The inverse of this figure will be the undercosting factor for hardware.

IV.1.2.2 Statistical validity of hardware undercosting factor r_p/r_u. Formal statistical analysis (beyond point estimation) is not valid for at least two reasons. First, there is no a priori knowledge of the form of the error term in the regression equation--for example whether it is additive or multiplicative. Nor are there adequate data points to derive the likely form. Second, the data

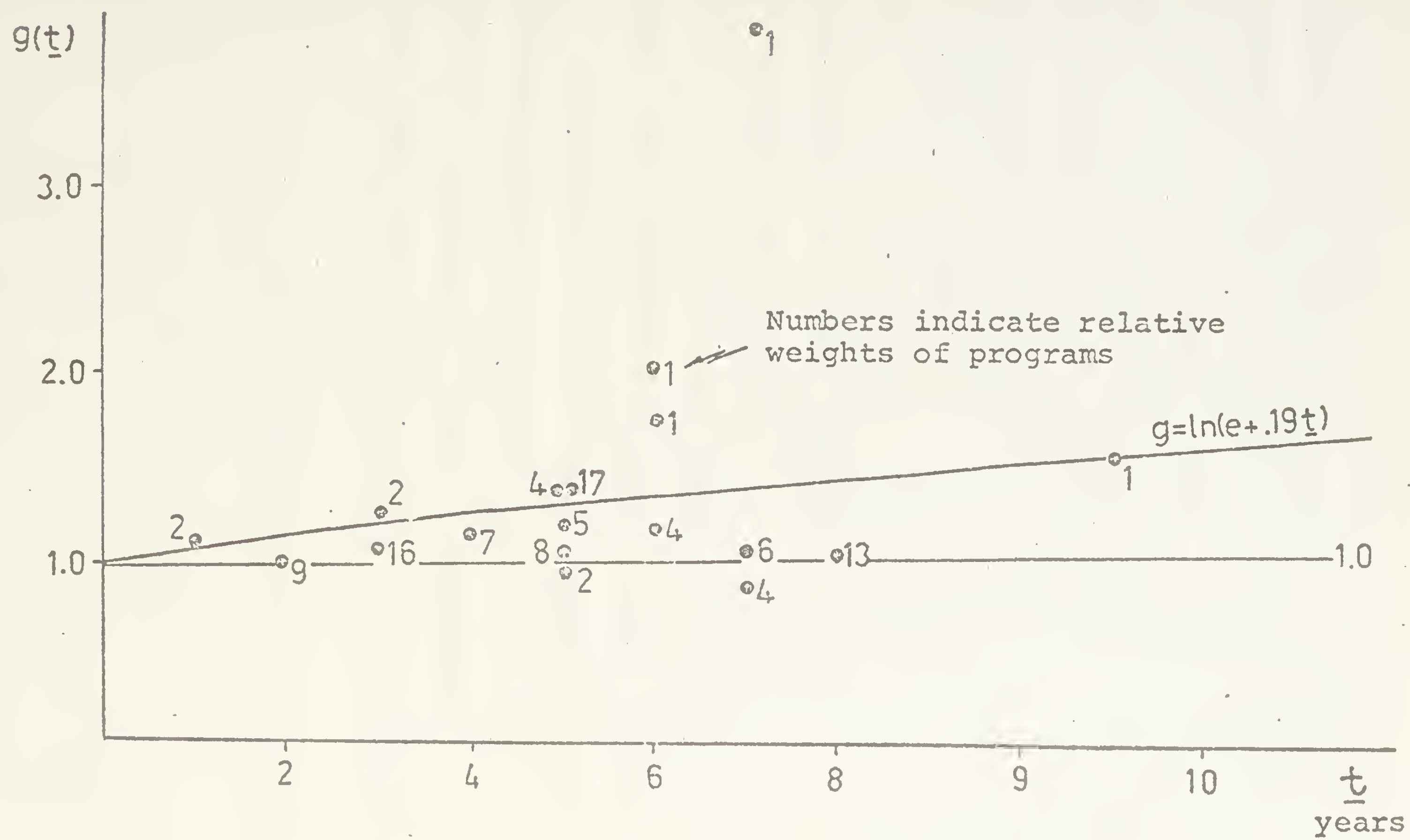

Figure 4 Cost growth as a fraction of initial per unit estimates versus time since program inception.

points are not independent. It seems to be the case that system costs can be altered by borrowing the appropriations from one program to shore up another.[53] Such "borrowing" is most feasible in the support areas. Transportation costs, for example, could be assinged to one program when goods are shipped for another. It may be the case that one program then grows relative to the others (see the extreme case, for example, of Condor on Table 2). The importance of such possibilities for the current study are that the observations are not independent, and thus parametric analysis is invalidated. Nonetheless "best fitting" in the least squares sense remains useful, for if one system is overcosted on a per unit basis due to borrowing from it, others must be undercosted. Including all systems will therefore still provide a reasonable relationship between cost growth and time.[54]

An ancillary argument in favor of considering cost growth on a <u>per unit</u> basis, rather than on the normal program

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[53]Hard evidence on this conclusion is not available, and the opinion must be considered the author's own based on circumstantial evidence only.

[54]A caveat is proper since "all" systems are not included in the analysis, specifically systems not yet under procurement may interact in the borrowing sense from those considered here. This type of borrowing is less likely, but possible. The possibility is considered less serious than the alternative of including developmental systems with their inherent costing inaccuracies. Also, see section V.3 concerning systems not included in the SAR process.

cost basis, results from the "borrowing" theory.[55] If one program is cannibalized to provide funds for another, the end result does not show up in program cost totals, for each will still be shown to cost their original amounts. But if the cannibalization results in a decrease in the amount of units eventually forthcoming in the cannibalized program, the effect will be reflected in the unit cost of weapons produced by that program. Thus Condor for example shows that the total program cost actually declined, yet because of the decrease in units, its per unit cost climbed dramatically.[56]

IV.1.2.3 The relationship between cost growth g and time t. The mechanics of obtaining the required relation between g and time since program inception t are the following. It is felt important to allow for convex and concave, as well as linear relationships, as cost growth will obviously be sensitive to the differences of the three curves demonstrated in Figure 5. This figure characterizes the following arbitrary one-parameter functions, one of which is to be selected:

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[55] Total program cost growth rather than unit cost increases are the basis for the analyses in [61], [62], [63], [76]. More recently, GAO has begun expressing growth in per unit terms [64].

[56] Condor is again used as an example because of its extremities, not for any specific knowledge of its program management. It is quite possible the per unit growth is due to non-linearity in unit costs relative to number of units produced.

$$g_a(t) = 1.0 + \gamma \underline{t} + d \tag{14}$$

$$g_b(t) = (1.0e^{\gamma \underline{t}}) \cdot d \tag{15}$$

$$g_c(t) = \ln(e + \gamma \underline{t} + d) \tag{16}$$

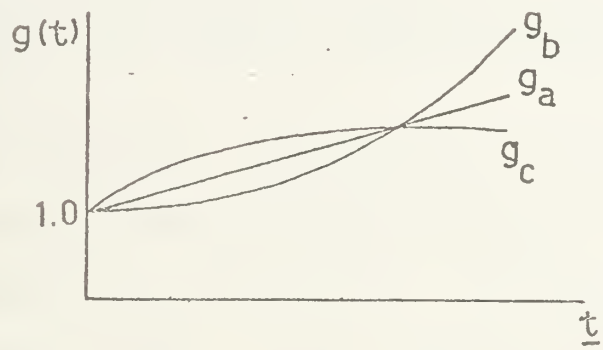

Figure 5 Characteristic cost growth relationships

In these, g is shown as a function of $\underline{t}$, e is the natural logarithm base, γ is the growth parameter, and d represents the residual of the <u>descriptive</u> linear regression.[57] The functional form of d is chosen to allow linearization of the three relationships. Each of the relations inherently yields a cost growth factor of 1 at t=0 (meaning at the time of the development estimate the cost growth <u>since</u> the development estimate is zero--an obvious requirement and one which does not have the usual problems associated with forcing the regression line through an arbitrary intercept point, for sta-

[57] See Goldberger [19, p. 157].

tistical tests are not to be invoked anyway). The form of $g(\underline{t})$ selected is to be the one yielding the largest coefficient of determination R^2. The estimate for the growth parameter γ then results from using the selected form of $g(\underline{t})$ in the least squares regression. This is an admittedly arbitrary decision rule which could be refined, but the insensitivity of the results probably makes refinement unproductive.

Table 4 provides the results of the various regressions. The logarithmic form g_b has the largest R^2, and yields the least squares estimate $\gamma^*=0.19$. To obtain the estimated hardware cost growth, a value for $\underline{t}$ is required for insertion into the formula

$$g(\underline{t}) = \ln(e + 0.19\underline{t}) \tag{17}$$

This $\underline{t}$ value is obtained by finding the average program length (wieghted by relative size) and arbitrarily taking 80% of the result. The 80% factor reflects the fact that the bulk of weapon units associated with a program are delivered sometime before the program ends.

The average program length obtained from columns (1) and (2) of Table 2 is 9.57 years. 80% of which is 7.66 years. The cost growth estimate for g, g*, is therefore 1.43 from (17), and the hardware undercosting factor 1/g* is 0.70. This value, which is the required estimate for r_p/r_u, can be compared with the value obtained for manpower

TABLE 4 -- Comparison of Least Squares Regression for Different Forms of g($\underline{t}$) Applied to Data of Table 2.

	Case a	Case b	Case c
Functional Form:	$g=1+\gamma\underline{t}+d$	$g=1e^{\gamma\underline{t}}d$	$g=\ln(e+\gamma\underline{t}+d)$
Linear Form:	$g=1+\gamma\underline{t}+d$	$\ln g=\gamma\underline{t}+\ln d$	$e^g=e+\gamma\underline{t}+d$
R^2:	.0155	<0	.0181
$\Sigma(g-g^*)^2$	10.63	11.41	10.19
γ^*:	.0313	.0233	.192

NOTE: The case b entry for R^2 can be negative since the forced regression line in that case worse approximation than the overall mean. Using $R^2 = 1 - \frac{SSE}{SST}$, SSE = sum of squared deviations, SST = total sum of squares, if SSE exceeds SST, then $R^2 < 0$.

undercosting, which was $w_p/w_u = 0.71$. The similarity of these values does not support hypothesis 1, which would require the manpower undercosting factor to be significantly lower than the hardware undercosting factor.

In Table 4, the quantities $\Sigma(g-g^*)^2$ for each functional form are presented to indicate the insensitivity of the results to the selected form. The relation between R^2 and $\Sigma(g-g^*)^2$ is not direct, but again the logarithmic form is slightly preferred.

<u>IV.1.2.4 Significance of results on hardware cost growth</u>. The most obvious elements of Table 4 are the extremely low values of the determination coefficient R^2. Normally this indicates the results are totally insignificant, and that while the estimate for the growth factor γ exists, no confidence can be placed in it. For research purposes we must agree that this essentially invalidates meaningful conclusions on hardware undercosting and therefore on cost bias. We can only conclude that the <u>estimates</u> for g and b do not support hypothesis 1, but by no means has it been disproved.

However there are some important matters left unsaid in that simple statistical summary. First, a glance at Figure 4 certainly indicates that cost growth, even with inflation and engineering adjustments abstracted, is positive. The low R^2 values only mean thwt there are other factors besides <u>t</u> affecting g. Low R^2 terms do not prove that <u>t</u> is unimportant.

Second, and most crucially, the low R^2 values may result because of program cost dependence, that is, borrowing from one program to make another look better can cause extreme variations in cost growth. This would cause lower values of R^2. Assume, for example, that the extreme per unit cost growth in the Condor system resulted largely because Condor was cannibalized to help other programs. Then the Condor cost growth factor g would be high and the programs helped would be lower. This effect causes variation in the data points. Abstracting Condor from the analysis as a "wild point" would raise the R^2 values significantly (recalling that R^2 reflects squared deviations), but is completely improper. With all programs retained in the analysis, if inter-program "borrowing" takes place then the sum of squared deviations from a regression line may be large, but at least the estimate for the average g value will not be compromised. Abstracting Condor would lower g*, but g* with Condor is more realistic.

Finally, simply abstracting inflation from the cost growths hides some problems. The SAR cost data is provided by the combined efforts of DoD personnel and contractors producing the systems. Both these components are naturally biased toward attributing cost growth to uncontrollable factors such as inflation rather than blaming their own estimation and planning abilities. It could well follow that the

cost growth estimates used to obtain Table 4 are understated ...but by how much is unavailable.[58]

Summarizing the discussion on cost bias, we can say the following. Both manpower and hardware seem to be undercosted. The best evidence is that such undercosting is approximately the same, leading to a conclusion that cost bias is near zero. This conclusion is founded, however, on very weak evidence from a statistical viewpoint. Hypothesis 1 is not supported, but cannot be rejected on statistical grounds.

IV.2 Investigation of Hypothesis 2

IV.2.1 The variables and causality. The cause of shifts over time in hardware/manpower ratios is assumed to be caused by changes in the factor price ratio. The elasticity of substitution (under the previously argued assumption of Hicks neutral technical progress) then becomes the parameter of central interest. Starting in 1955, data on government asset value has been required by the U.S. Congress' House Committee on Government Operations. The availability of this data allows empirical exercise of the models presented in the previous chapter.

Table 5 provides the time series data between overall hardware/manpower ratios $(H/M)_t$, estimated incremental hardware/manpower ratios $(h/m)^*_t$, and $(w/r)^*_t$, which represents the

[58] Such undercosting bias is inherent if not explicit in the evidence provided in Ronald Fox's informative study on Defense system acquisition [16, especially pp. 159-165].

term $[(w/r)_t/(w/r_0)]$ of equation (11). These series result from independent evaluations of hardware, manpower, and their annual increments, with 1967 as the base year. The details of the data sorting and adjustment are largely contained in the appendix, as the source note to Table 5 indicates. For now, it will perhaps aid the discussion to give examples of how each of these quantities is ultimately obtained from the tables, and to review their definitions.

$(H/M)_t$ is simplified notation for (H_t/M_t). H_t is obtained from Table 13, column (5), and represents the total value of Navy hardware assets at time t in 1967 dollars. M_t is obtained from Table 27 and represents the actual number of men required to man the H_t level of hardware. Therefore $(H/M)_t$ is the hardware/manpower ratio associated with all systems in the weapon stock at time t (the term "system" includes both hardware and manpower--an aircraft is not a system unless it is manned).

Gross new hardware delivered in period t, h_t, and manpower m_t required by h_t, cannot be directly obtained because of the myriad system procurements which occur, and because of the interdependencies between system utilizations of the input factors. However the annual expenditures shown in the U.S. Budget for new system procurement provide estimates for gross expenditures in period t, designated h_t^* and presented in Table 12. If expenditures are assumed to match deliveries,

then these plus the sequential values for $(H/M)_t$ provide the $(h/m)^*_t$ estimates. This process is explained in Table 11's comments. The $(h/m)^*_t$ values of Table 11 represetn the induced hardware/manpower ratio associated with the gross addition h_t to hardware stock H_t. They therefore serve as an estimate for $(h/m)_t$. They also reflect the assumptions of the previous chapter that retired hardware has the inherent factor ratio $(H/M)_t$.

The price ratio $(w/r)^*_t$ is obtained from Table 9, column (5). There is an assumption relating hardware procurement costs and rental costs in this ratio which should be made explicit. M_t is the manpower required at time t and w_t is its cost per man-year, that is w_t is the "rental" cost of manpower. On the other hand H_t is hardware stock and r_t should, for consistency, also be the rental cost of hardware. Yet the Commerce Department price indices for hardware goods are based on purchase prices rather than rentals. In this study, the importance of the (w/r) ratios lies in their trends rather than their absolute values. Therefore the values $(w/r)_t$ and $(w/r)^*_t$ can be validly used so long as the following assumption holds: Hardware purchase prices and hardware rentals are directly related. More formally, hardware rentals are linearly dependent on purchase prices.

TABLE 5 -- Derived Annual Values for Overall Hardware/Manpower Ratios (H/M), Incremental Hardware/Manpower Ratios (h/m)*, and Cost-of-Manpower to Cost of Hardware Ratio (w/r)*.

Fiscal Year	H/M (1)	(h/m)* (2)	(w/r)* (3)
1955	(45.17)	--	0.89
6	44.87	41.55	0.85
7	42.25	16.71	0.83
8	39.78	22.19	0.83
9	39.85	40.48	0.86
1960	44.95	94.31	0.86
1	47.35	66.63	0.88
2	50.49	76.01	0.88
3	53.88	76.23	0.89
4	55.18	65.53	0.94
1965	56.88	74.04	0.96
6	54.41	29.30	0.99
7	55.47	65.17	1.00
8	58.30	81.21	1.00
9	57.12	48.22	1.03
1970	60.21	84.59	1.11
1	63.61	92.31	1.13
2	62.99	57.89	1.25
3	62.67	59.88	1.34
4	61.98	55.29	(1.36)

NOTES: Column (1) is the ratio of column (5) of Table 13 to the M_t values of Table 27. Column (2) is derived in Table 11. Column (3) is obtained from Table 9.

IV.2.2 Intuitive Observations on H/m, h/m, and (w/r)*. Table 5 is visually presented in Figure 6, which is a semi-logarithmic plot. There are several points of interest available from this figure. Most of these will be investigated quantitatively, but a preliminary glance is illuminating.

IV.2.2.1 Consistency in w/r trends and resulting implications. Since $(w/r)^*_t$ and $(w/r)_t$ are directly related, the terms will be used interchangeably in much of the following. First, there is a rather consistent exponential rise in wage/hardware cost ratio w/r, which is accompanied by a less consistent, but still obvious rise in H/M. Notably absent is any step increase in w/r, such as might be expected in 1968 when federal wages were raised to provide comparability with private industry.[59] The smoothness of the w/r trend prevents any verifiable conclusions about the form of technical progress. Has a discontinuity occurred, then a (lagged) response to this discontinuity by the hardware/manpower ratios would have allowed determining how much of the rising trend could be attributed to price changes (substitution

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[59] Congressional legislation pegged federal salaries to the Department of Labor's Professional Administrative and Technical (PAT) Survey. The transition was to start in November 1967 and be completed by July 1, 1969. Large pay increases in fact occurred in fiscal 1968 [73, p. 135], but indices for capital goods increased comparably, as can be seen from columns (1) and (4) of Table 9. Note July 1, 1968, is the end of fiscal year 1968 in that table.

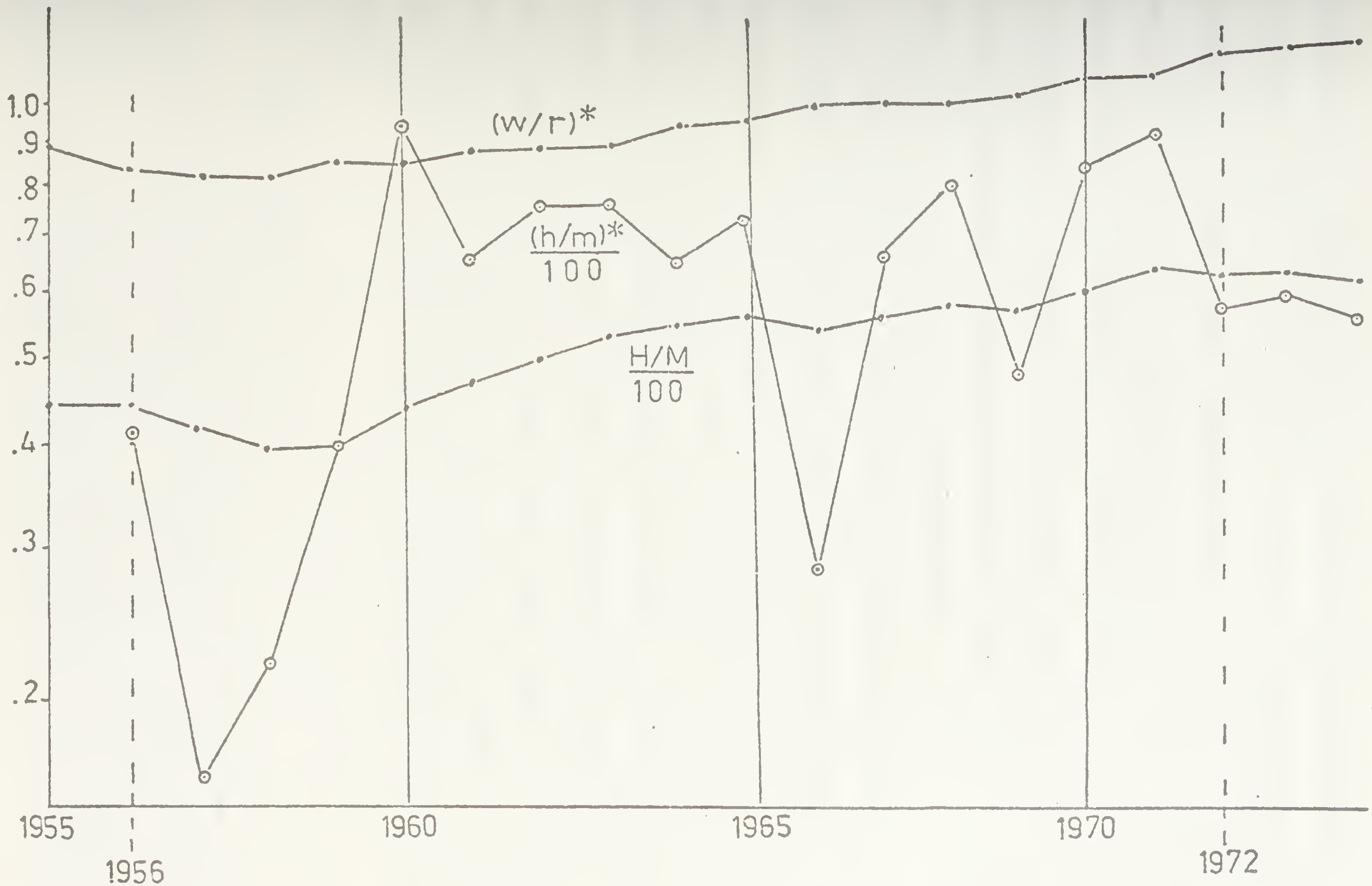

Figure 6 Derived relationship between H/m, (h/m)*, and (w/r)* for 1955-1974

elasticity), and how much to labor-saving technical progress.[60] A sudden rise in w/r with no change in the h/m trend or the lagged H/M trend would indicate that hardware/manpower ratios respond to the bias in technical progress only, and that prices have no effect.[61] A rise in h/m and lagged H/M that proportionally matches the w/r rise would indicate a substitution elasticity of unity (assuming the trend increase in both time series had been abstracted).

In contrast to the lack of response of w/r to the 1968 pay increases, the fiscal 1972 All-Volunteer Force (AVF) program seems to be reflected in the slight rise in w/r after 1971. Unfortunately, 1972 is too recent for any effects in H/M to be considered, especially since the end of the Vietnam conflict confounds the data. Follow on studies can investigate the AVF effect, though they will tend to also be confounded by the fact that high inflation rates coincided with the AVF, so the w/r rise is not so dramatic as it might have been.

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[60] See section II.7.1.

[61] Defense is still considered a price taker. It must be added that if technical progress is of the induced form (see section II.7.2) then a resulting change in hardware/manpower ratios may result. The only perceptable difference then between substitution effects and induced technical bias would be a longer time lag until response if technology must be developed (induced) rather than available already (substitution).

IV.2.2.2 Post-war disruptions in the data. Post-war periods have disrupting effects of the data, though the disruptions do provide insights. If 1965 and 1972 are taken to be the first post-war years for Korea and Vietnam, then the H/M ratio is seen to decrease noticeably for the subsequent three years in both cases. While that is consistent with the 1956-60 drop in the w/r trend, it is not consistent with the post-Vietnam w/r data. A likely interpretation is that post-war sentiment produces an overwhelming political force, which temporarily drowns out purely economic considerations. Popular demands to "stand-down" from the war posture manifest themselves in large cutbacks in weapon units after a war,[62] regardless of what relative prices do. For contractual reasons weapon cuts cannot be matched by equivalent manpower cuts, as enlistment terms must be honored. Furthermore, servicemen are less anxious to leave the military when the economy is unhealthy. In both post-war periods GNP declined.[63] Such periods cause downward Defense budget pressures and less desire for servicemen to leave their secure military jobs. Both these phenomena can be simultaneously accommodated by large cutbacks in military hardware relative

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[62]Total active ships, for example, dropped from 973 to 890 between 1956 and 1958, and from 702 to 593 from 1971 to 1973. In neither case was there an equivalent drop in manpower. See Tables 15 and 28.

[63]See [30, p. 1] for a comparison of the two post-war economics.

to military manpower, providing an explanation for the post-war trends.

Considerations such as the above make it important to select the data base carefully. A biased result would occur if the entire time span of available data from 1955 to 1974 were used. Instead, the conclusions will rely on the perhaps obvious cycle from the end of the Korean war to the end of Vietnam, that is, from 1956 to 1972. The quantitative results will be derived accordingly.

IV.2.3 Putty/clay and the capital intensity/labor intensity argument again. Before turning to those, however, Figure 6 provides further insights which may help place the underlying theory in perspective, especially the "putty/clay" character of the assumed model. To do so requires a comparison of the h/m and H/M series of Figure 6 (or Table 5).

The relation between h/m and H/M demonstrates two effects, both resulting from the putty-clay assumption. First, since any change in the overall H/M ratio is embodied in new equipments, the H/M ratio can only fall (rise) if h/m is less than (greater than) H/M. Second, given the direction of movement of H/M, the gap between H/M and h/m for any given year will be inversely related to the size of that year's procurement expenditure. Thus, if expenditures (new systems) are small relative to existing hardware, then a unit rise in H/M will require a higher h/m embodied in the new systems than if ex-

penditures were relatively large. These comments can be demonstrated more formally. Analyzing equation (10) of Chapter III the following can be derived:

$$(H/M)_{t+1} = \frac{(H/M)_t [H_t(1-\delta)+R_t]+(h/m)_t h_t}{H_t(1-\delta)+R_t+h_t} . \qquad (10)$$

Therefore

$$\Delta(H/M)_t \simeq (H/M)_{t+1} - (H/M)_t = \left[\left(\frac{h}{m}\right)_t - \left(\frac{H}{M}\right)_t\right]\left[\frac{h_t}{h_t+\underline{H}_t}\right], \qquad (10')$$

where $\underline{H}_t = H_t(1-\delta) + R_t$.

$\underline{H}_t$ represents hardware carried forward at time t.

The first factor of (10') in brackets shows that the directional change of H/M depends on whether h/m exceeds H/M. The second factor shows that the rate of change in H/M depends on how large gross new investment h is compared to carried forward stock $\underline{H}$.

1st factor

2nd factor

The close relationship between h/m and H/M is important for analytic reasons. Under conditions of substitutability ex ante <u>and</u> ex post (putty-putty)[64] the H/M time series could be regressed against the (w/r)* series without major violation of underlying statistical assumptions, specifically the independence of observations. At each time point, the proper ratio of H to M would be based on the usual mar-

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[64]Plus the usual assumptions of perfect competition, including the alternative of trading existing assets at market value for substitutes--or equivalently, if capital is "Perfectly malleable".

ginal productivity concepts, and H/M ratios would track $(w/r)^*$ ratios depending on the elasticity of substitution λ. If the implicit production function had constant elasticity λ, then λ could be estimated and statistically tested from a knowledge of H/M and $(w/r)^*$ only.[65] This would be completely valid only if hardware in stock and manpower were exchangeable each year--i.e., if the economic requirements of perfect competition prevailed. But since a large amount of any one year's system are those already on hand from the previous year, one runs into the following difficulty when H/M and $(w/r)^*$ are compared directly: if defense budgets are squeezed to the point where no new procurement occurs (h_t=0) then the fixed factor assumption means H/M cannot change with $(w/r)^*$. The conclusion then that λ was zero, which follows if capital is costlessly malleable, would be wrong. Less extremely, if procurement budgets are small, then H/M cannot change very much, and would be underestimated. It seems important, then, that only the incremental acquisitions, that is h/m, be compared to $(w/r)^*$ changes.

Therein lies one possible explanation for the inconsistencies between operators who claim equipment has become too sophisticated (indicating excessive capital intensity), and analysts who claim a need for greater capital intensity--the controversy which inspired the present research.

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[65]This is the approach implicit in [86].

The former base their conclusions on the new goods they are provided, the latter on aggregated goods, old and new. The divergency of viewpoint is strengthened if new procurement is decreasing as a fraction of total asset value, a fact of recent budget trends.

The argument for comparing $(w/r)^*$ to h/m instead of H/M can more formally be stated by noting that $(H/M)_t$ is highly dependent on $(H/M)_{t-1}$. The normal statistical approach to such autoregressivity is to use first differences of the time series.[66] From equation (10), it is apparent that h/m is a function of the first differences of H/M, so we shall remain close to standard theory. However, we will not want to take first differences of the dependent variable $(w/r)^*$ as would be standard if the intertemporal dependence was between sequential random errors.[67] Instead, h/m will be regressed on $(w/r)^*$ directly.

It can be seen that the putty-clay model manifests itself analytically in the H/M, $(h/m)^*$, $(w/r)^*$, relationships. The extreme variability inherent in h/m compared to H/M will produce less confidence in any estimate for λ. More importantly, the large stock of hardware carried forward from year to year means that values of λ derived from $(h/m)^*$ trends will be significantly larger in magnitude than those derived

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[66] See Goldberger [19, pp. 236-8].

[67] Ibid., equation 4.34.

from H/M trends.[68]

<u>IV.2.4 Quantitative Results</u>. The data in Table 5 is analyzed in statistical terms in this subsection. The main point will be to estimate λ based on equation (11) of Chapter III, and repeated here:

$$(h/m)_t = [(w/r)_t/(w/r)_0]^{\lambda} \ (h/m)_0 \tag{11}$$

or $$(h/m)_t = A'[(w/r)^*_t]^{\lambda} \tag{11'}$$

where $A' = (h/m)_0$, $(w/r)^* = [(w/r)_t/(w/r)_0]$ and the base year 0 is 1967. To stress some of the previous comments, the regression of H/M on $(w/r)^*$ will also be presented.

In order to utilize (11), several assumptions must be invoked. First, changes in h/m are caused by changes in $(w/r)^*$. Also, observations on h/m result from (11), and multiplicative error terms ε which are independent log-normally distributed. For estimation purposes, (11') becomes:

$$(h/m)_t = A'[(w/r)^*_t]^{\lambda} \cdot \varepsilon.$$

The assumption of log-normality is justified by calling on the Multiplicative Central Limit Theorem, which, stated non-rigorously, ensures that the distribution of products of in-

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[68]An analogous situation evolves if shifts in factor ratios are attributed to technical bias. The bias factor must be larger if technical progress is embodied in new machies than if progress is disembodied. A closely related example is in Solow [51, p. 95], especially his conclusion that estimates of the technical progress growth factor are lower for disembodied progress than embodied progress.

dependent random variables tends toward log-normality in the limit [19, p. 216].

The distribution of the error term allows linearizing (11) into the following form:

$$\ln(h/m) = \ln A' + \lambda \ln(w/r)_t^* + \ln\varepsilon$$

If $\ln x = x^+$, this becomes

$$(h/M)^+ = (A')^+ + \lambda[(w/r)^*]^+ + \varepsilon^+$$

To utilize the classical linear regression model, ε^+ must be normally distributed with mean 0 and constant variance σ^2, which is consistent with the assumption that ε is log-normal.

Since only the economic effects of changes in factor price ratios are being considered, we should expect the error term ε^+ to be large. It must absorb the effects of such elements as political, bureaucratic, and technical factors which unpredictably effect hardware/manpower ratios. That the factor price ratio can only explain a limited amount of the variation in h/m will be inherent in the small R^2 of the results.

It should be stated explicitly that the series (h/m)* and (w/r)* (as well as H/M) are <u>assumed</u> to be the correct series for the quantities they represent. However, as the appendix will clearly indicate, the derivations of these series are necessarily indirect. While these are based on the rationale presented in Chapter II, the absence of an

output measure for "National Security" means that these derivations are sometimes arbitrary, and possibly contain unknown biases. The results must be interpreted, therefore, with caution. The data manipulations are included in an appendix because of the dry detail involved--but the research results are based on these details, and the appendix is therefore central to the conclusions.

IV.2.4.1 The estimates for substitution elasticity λ. The results of the various regressions are presented in Table 6. The multiplicative factor A in each case is unimportant, but can not be pre-specified without seriously biasing the estimate for λ by forcing the regression through an arbitrary intercept. It is therefore included in the estimation process. Since 1967 is chosen as the base year for (w/r), then A' represents the regression intercept at time 1967.

According to the model selected, the elasticity of substitution is estimated using the data of Table 5 by the maximum likelihood estimate $\lambda^* = 1.74$. This coincides with the incremental (putty-clay) model for the 1956-72 time period. The coefficient of determination R^2 is low as must be expected, and the 90% confidence interval includes the value $\lambda=0$. This means, in a hypothesis test of $\lambda=0$, that the hypothesis cannot be rejected.

The incremental model for the 1955-74 period yields a

TABLE 6 -- Results of Regressing Forms of Hardware/Manpower Ratios On Factor Price Ratios for Alternative Time Periods.

Model	$H/M = A[(w/r)^*]\varepsilon$		$h/m = A[(w/r)^*]\varepsilon$	
Time Frame	1955-74	1956-72	1955-74	1956-72
MLE for λ	0.855	1.13	0.952	1.74
90% Conf. Int. for λ	(0.64, 1.07)	(0.86, 1.40)	(-0.27, 2.17)	(-0.02, 3.50)
Coef. of Det. R^2	0.722	.775	0.098	0.167
MLE for A'	52.98	54.93	55.70	59.86

NOTES: Results obtained from data included in Table 5.

"MLE" is Maximum Likelihood Estimate.

λ^* of .952, and the hypothesis $\lambda=0$ again cannot be rejected at the 90% level with this data. The lower value of λ^* is due to the drop in h/m ratios following the Vietnam War. The result is felt to be biased downward by including two post-war periods but only one war (Vietnam).

The results for the H/M model are statistically satisfying as evidenced by the large R^2 and smaller confidence intervals, but are considered invalid for the reasons previously given.

Overall, the evidence does not allow rejecting, on a statistical basis, the hypothesis that the substitution elasticity is zero. Nonetheless, the maximum likelihood estimate for substitution elasticity in the 1956-72 time frame is 1.74. This certainly suggests that capital intensification has occurred. More obviously, while the hypothesis $\lambda=0$ cannot be rejected, there is little in Table 6 that <u>supports</u> the hypothesis.

<u>IV.2.5 An oversight, and Fellner's first proposition.</u> To avoid clouding of an already complex analysis, an important factor has been ignored. This was done largely because the factor could not be accounted for empirically. The discussion will lead back to Fellner's first proposition relating to the foresight of planners (see section II.7.3).

We have assumed that h_t, the gross new hardware obtained in period t is estimated by the procurement expendi-

tures of period t. That in itself is not totally accurate, but there is a more important matter implicit in that assumption and the use of equation (11) to estimate λ. Systems delivered in period t are not used only in period t, but have a long expected life. Assume this life span is the same for all systems and is 10 years. Then it is not only $(w/r)_t$ which should determine the h/m ratio, but some combination of $(w/r)_t$ through $(w/r)_{t+10}$. This combination is felt impossible to determine, and the present research avoids the entire issue of how one properly combines series of inputs with series of outputs.[69] Rather, the following rationale is implicitly used.

Empirically, w/r ratios have historically risen over time (see Figure 6). If planners count on this rise, then they will, in accordance with Fellner's first proposition, choose systems more capital intensive than is indicated by the prices at delivery time. This follows since the above derivations for λ are based on delivery times, since "delivery times" are the beginning of the system utilization period, and since w/r is expected to rise during that period. If planners integrate these rising prices into their decisions, but the analysis does not, then the estimates for λ will reflect the analytic oversight by seeming high. Spe-

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[69]Sir John Hicks explores the matter in his 1973 book, which is based on the problem. He develops "...an elementary process that converts a sequence...of inputs into a sequence of outputs." [27, p. 8].

cifically, equation (11) utilizes $(w/r)_t$ as the ratio influencing planners, while planners implicitly use some integrated value of $(w/r)_t$ through $(w/r)_{t+10}$. This integrated value will exceed $(w/r)_t$; if it were used instead then the estimate for λ would be lower.

But this conceptual problem should be viewed within the overall priorities of the research. Factor ratios were shown, in Chapter I, to be popular with defense analysts and critics. This research has tried to base such ratios and their use on some reasonably acceptable theoretical basis. The fact that the models developed are not perfect should not imply they are of no value at all.

In the next chapter some of the above conclusions, their implications, and some further cautionary matters, will be presented.

CHAPTER V

CONCLUSIONS, INTERPRETATIONS, AND CAVEATS--A SUMMING UP

V.1 Conclusions

Two models have been developed on what seem to be reasonable theoretical grounds. The first model compares at some point in time planned hardware/manpower ratios $(h/m)_R$ with economically proper ratios $(h/m)_U$. This is done in equation (7), which is repeated here.

$$(h/m)_R = b^{\lambda} \cdot (h/m)_U \tag{7}$$

In (7), b is a measure of cost bias and λ is substitution elasticity.

The second model compares hardware/manpower ratios at different time points. Equation (13) is a function of changes in price ratios and substitution elasticity:

$$(h/m)_t = [(w/r)_t/(w/r)_0]^{\lambda}(h/m)_0 \tag{11}$$

These models could be used to predict the effects of changes in policy which affected cost bias or changes in anticipated price ratios if the parameter b and λ were known. Since they were not, the research instead opted to estimate them using U.S. Navy data.

It was found that <u>both</u> manpower and hardware have been priced, by planners, at approximated 70% of true accounting value, thus indicating zero cost bias, or b*=1. However no

confidence interval on b* could be obtained because the classical assumptions did not hold.

Under the assumptions of putty/clay capital accumulation and therefore embodied technical change, the best estimate for substitution elasticity λ was found to be $\lambda^*=1.74$, with 90% confidence interval (-0.2, 3.50) for the 1956-72 data base. If technical change was not attributed only to new systems (that is if it was disembodied), then the estimate for λ^* was as low as .855, with 90% confidence interval (0.64, 1.07) for the 1955-74 base data. It is obvious (see Table 6) that both the embodiment question and the time frame considered have important effects on any interpretation of capital/labor changes.

Enroute to the estimate for cost bias b, it was found that cost growth in weapon system acquisition is directly related to time since program inception, but seems to display diminishing marginal increases. This is demonstrated in Figure 4, which shows the best estimated relationship

$$g(t) = \ln(e + .19\underline{t}) \tag{17}$$

to be increasing (positive first derivatives) with diminishing slope (negative second derivative). The data tends to support the theory thatsystem cost growth is most dominant in the early stage of a program--perhaps because of pressures (by DoD, Manufacturers, and some Congressmen) for low estimates. If the estimates are artificially low, the

cost growth will become apparent quite early in the production cycle. However, the data is so weak statistically that one can only say this <u>may</u> be the case. Stronger conclusions than this are not supported by the data.

V.2 Interpretations

The above empirical results of course prove nothing conclusively. Policy changes based on them would not be advised without further research. They do, however, serve to cast doubt on what may be preconceived theories for improving DoD efficiency. Since preventing erroneous policy may be as useful as prescribing valid policy, the effort seems worthwhile.

Saving reservations on the conclusions for a later section and proceeding as though they are completely valid, the following interpretations emerge.

<u>V.2.1 Policies which improve estimation for only one factor may be counterproductive</u>. While admittedly simplistic, equation (7) above should at least be considered before major changes to hardware or manpower costing procedures are finalized. If manpower, say, is undercosted by only 5% in the future while hardware is undercosted 30%, then system acquisition (recall that "systems" include both men and machines) may become more capital intensive than is proper. The reasoning is obvious. Manpower suddenly <u>seems</u> more ex-

pensive to planners, so they purchase systems which use less of it. In terms of (7), b becomes greater than unity (b's definition was $(w_p/w_u)/(r_p/r_u)$), and $(h/m)_R$ exceeds $(h/m)_U$, the economically correct h/m ratio.

The above example is relevant. Recent and current discussions on the military pay system concern shifting to a salary type scheme wherein the various current "fringe" benefits (medical, housing, retirement, commissary, etc.) come out of the individual's pay.[70] Such policy would no doubt make it difficult to ignore manpower costs, but a classical problem of "second-best" could result. If both factors cannot be priced properly, it at first seems second-best to price <u>one</u> correctly. But if the goal is efficiency, it may be better to price both equally incorrectly than to choose the second best solution. Of course, the best action is to ensure that both factors are properly costed.

<u>V.2.2 Arguments for greater capital intensity may be ill-founded</u>. The results of Table 6 seem to show that if anything, the rising trend in manpower costs relative to hardware costs have been answered with strong responses toward capital intensity--at least within the flexibility open to Defense planners. This tends to confirm statements by some Navy operating personnel that new systems are per-

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[70] See Binkin [5], for comments along this line and past proposals, such as the Hubbell pay plan.

haps over-sophisticated.

Only if the total hardware held by the Navy is considered, and the artificial 1955-74 time frame is considered,[71] does substitution elasticity seem low enough (0.85) to claim that response to rising labor prices has been inadequate. There are many caveats to that statement, and they will be stated in the next section.

For now, it should at least be valid to say there seems grounds for synthesizing the two divergent viewpoints which opened this study. If one considers system changes to be disembodied, that is occuring to all systems held, then a lower rate of change of the hardware/manpower ratio has occured than if technical changes are assumed embodied in new systems only. This result, somewhat obvious on hindsight, is not clear from the literature commonly published by analysts of Defense matters, some of which was discussed in Chapter I.

Furthermore, the result rests totally on the putty/clay assumption. It is not altered by comments on what the correct substitution elasticity λ is. Nor is it altered if λ is variable, if the production function is non-homogeneous, or if the production function itself varies over time.

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[71] 1955 was a peak war year for Korea and 1974 was a post-war lull as far as U.S. military activity was concerned. The arguments for using 1956-72 are voiced in section IV.2.4.

These matters warrant discussion, but the apparent divergence between those arguing for greater capital intensity and those advising less can be synthesized even with the crude data available: The former could implicitly be considering total systems over one time frame, the latter incremental systems over a different time frame. The former could then obtain a substitution elasticity of 0.85, the latter one of 1.74. Then, if it is taken that substitution elasticity is constant and unity (the "Cobb-Douglas" assumption) each party justifies its argument. Even if $\lambda \neq 1$, there is still a basic difference in the viewpoints, though it may become one of degree rather than kind.

V.3 Some Caveats

There have been numerous assumptions made in arriving at the tentative results of this study. It is time to highlight some of the more critical ones. They can be separated into theoretical issues and budgetary issues.

V.3.1 Theoretical caveats. The theoretical caveats can be mentioned rather quickly, so long as it is stated that any or all of them could invalidate the results, but do not necessarily do so. Many have been mentioned previously. Here we stress some which were not.

First, while λ^* values ranging from 0.85 to 1.74 are estimated, there is no precedence for an assumption on the

proper range for substitution elasticity in Defense. The fact that $\lambda=1$ may be correct for the economy's production of output can not be used to conclude a similar figure holds in DoD's production of "National Security." Furthermore λ need not be constant. We can stay on the safe side by assuming the estimate desired was for a limited range of hardware/ manpower values.

Homogeneity in the hardware factor has been treated rather strangely. It has been assumed that new hardware (h_t) is homogeneous, and that old hardware H_t is homogeneous, but that they are not homogeneous with each other since they have different manpower requirements. But then, once the new hardware is obtained, it becomes part of the old hardware, and the new and old combine to form the total hardware stock. This stock is now homogeneous again, and has a manpower intensity which is a weighted average of the two previous quantities (h_t and H_t). This type of hardware seems very convenient, being homogeneous when needed and then changing into a new homogeneous form at command. Whether such an assumption is acceptable or not is a personal choice. Homogeneity is implicit in some form in all aggregate models of physical capital, and is one reason why such models are not favored by many economists.[n] Suffice it to say that the

[n]Harcourt and Liang survey this controversy on capital theory in their introduction [22, pp. 9-44].

current study uses averaging techniques which may be invalid in the opinions of many (can machines which use much labor be averaged with machines which use none to yield machines which use "some"?).

On the cost bias portion of the study, it should be mentioned that the hardware costing considerations of section IV.1.2 were based on major weapon systems, since they are carefully monitored in the SAR process. However minor systems (not in SAR) account for more expenditures than those in SAR. Reference [62] claims they comprise about 3 times the expenditures of major systems budget. It has been assumed here that the cost figures for SAR systems are representative of all systems. This may or may not be so. While a detailed analysis of the difference is not the present purpose, some evidence is available from [62].

In that study, the General Accounting Office (GAO) finds that over half of the minor systems studied had cost growths in excess of 50%, with the overall range of 16% to 213% [62, p. 2]. It seems apparent from the study that minor systems have cost growth problems similar to major systems, and in fact the GAO's recommendation was that DoD should subject minor systems to procedures similar to the SAR process in order to control costs.

V.3.2 Budgetary caveats. The most important matter left unsaid in the research is probably the treatment of

Research, Development, Test, and Evaluation (RDT&E) funds. A glance at Table 7 shows that RDT&E is a substantial part of the Navy budget: about 10% of the total in 1963 and 9% in 1973. Yet R&D (for short) has not been included in our evaluation of hardware or manpower. The reason is that this allotment is practically impossible to assign to either weapon components or even to years. R&D expended this year may be reflected in next year's hardware, or in something to arrive in 20 years, or in something that never arrives at all...for example, how does one allocate the funds spent unsuccessfully developing the nuclear bomber. Also perplexing is the difficulty in determining how much of the R&D funds should be attributed to <u>manpower</u> development.

There are at least two conceptual ways to handle R&D expenditures. One is to assume it is essentially spent in hardware development (which seems to be the case) and to then increase the hardware value accordingly. Doing this would probably not affect the present results seriously, since the <u>changes</u> in ratios of hardware to capital would be very similar, though the time phased ratios $(H/M)_t$ and $(h/m)_t$ would be larger in absolute value for all t.[72]

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[72]For example $[(h/m)_1 (h/m)_2]$ and $[a(h/m)_1/b(h/m)_2]$ are equal if a=b. Since R&D only changed from 10% to 9% of the budget in 10 years, it would seem major changes in h/m ratios would not result by inclusion of R&D. (h/m) would be greater in each case by about 10%, i.e., $a \doteq b \doteq 1.1$.

A second way to treat R&D, and the way it is implicitly treated in this study, is to essentially abstract it as follows. Assume that R&D is the price for ensuring "proper" system development. This means that appropriate alternative systems exist to choose from. Thus, if changes in price ratios are anticipated, R&D funds are used partly to develop the types of systems which allow factor substitution to take place. This borders very much on the theory of induced technical progress. With R&D abstracted as a constant fraction of the budget, R&D can be assumed used to ensure enough alternative systems exist, and exist at the right time, to let substitution between factors occur. Seen in this way, the difference between induced technical progress and factor substitution--an issue discussed in some detail in section II.7--becomes even less distinct, confirming the view that their difference is more conceptual than practical.

Shifting to another budgeting caveat, this study has not made a clear distinction between expenditures and appropriations. The oversight may be significant in view of the early assumption that Defense budgets are fixed. In fact, <u>appropriations</u> are what are fixed, while expenditures, the annual payments made and justified by appropriations, are not fixed--they must only add up, eventually, to the appropriation limit. All that can be said in favor of treating expenditures as fixed is that appropriations are <u>justified</u> on the basis of

planned expenditures, and so long as programs proceed on schedule, the planned expenditure phasing is fixed. The seriousness of error in this assumption cannot be estimated at this time.

The problem also comes into play because new hardware for year t, h_t, is estimated from the actual expenditures in year t, rather than the expenditures <u>planned</u> for year t in some earlier year such as t-10. If expenditures do not match system delivery (such as if a firm is paid in advance to keep it solvent) then inaccuracies obviously result. All that can be done for both these problems is to assume that they are not overwhelming causes of bias in the results.

V.4 Closing Statement

In dealing with a subject so large as capital and labor tradeoffs in Defense, it would be impossible to itemize all the assumptions and caveats which exist. Whatever the hidden problems, however, there does seem reason to at least consider the major indications of this research, which are here repeated:

(1) Cost bias does not seem to have been significant in Defense hardware and manpower costing. Policies which change that balance should be considered carefully.

(2) System accumulation has been such that capital/labor ratios embodied in new systems are increasing faster than labor/capital <u>cost</u> ratios. Therefore arguments for

even greater weapon sophistication may be premature.

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NOTATION AND ABBREVIATIONS

Notation: (Subscripts and superscript symbols are listed individually in alphabetical order or at end of section.)

B: The fixed annual budget.

b: Cost bias specifying proportional undercosting of manpower relative to hardware. $b = (w_p/w_u)/(r_p/r_u)$.

c_t: Capital/Labor ratio associated with hardware being retired.

d: Residual in descriptive linear regression.

$g(\underline{t})$: Unit Cost growth g, denoted as function of time since program inception $\underline{t}$.

H_t: Hardware stock at time t, valued in 1967 replacement cost.

$\underline{H}_t$: Hardware in stock at time t-1 and remaining at time t. $\underline{H}_t = H_t(1-\delta)+R_t$.

H/M: Ratio of hardware stock to its manpower requirement.

h_t: New hardware delivered during period t, where period t is from time to to t+1, measured in 1967 dollars.

h/m: Ratio of new hardware to its manpower requirement.

K_t: Capital Stock at time t.

k_t: Hardware stock retired in period t.

K/L: Capital/Labor ratio.

L: Labor requirement.

M: Manpower requirement for H.

n: Definition wholly contained in Table 15.

p: Subscript indicating planning prices, which are prices assumed by planners to be in effect at time of system delivery.

NOTATION AND ABBREVIATIONS (Continued)

R_t: Repair funds expended in period t. Also has definition contained in Table 15.

r: Unit price of hardware or capital input. Also has special definition wholly contained in Table 15.

t: Historical time index.

$\underline{t}$: Time since program inception.

u: Subscript indicating prices actually in effect at time a system is delivered.

w: Unit price of manpower or labor input. Also has special definition wholly contained in Table 15.

$(w/r)_t^*$: The ratio of $(w/r)_t$ to $(w/r)_{1967}$, where $(w/r)_t$ is the factor price ratio in year t.

δ: Annual physical plus tactical depreciation rate for hardware.

ε: Random error term.

γ: Cost growth parameter for system cost growth.

λ: Elasticity of substitution.

σ^2: Variance of random variable.

+: Logarithmic superscript, i.e. $y^+ = \ln y$.

: Superscript indicating estimated value. Y is an estimate for Y. (w/r)* has the special meaning above.

Abbreviations:

AVF: All Volunteer Force

DoD: Department of Defense.

O&M: Operations and Maintenance.

NOTATION AND ABBREVIATIONS (Continued)

Abbreviations (Continued)

PPR: Federal Real and Personal Property Inventory Reports.

RDT&E: Research, Development, Test, and Evaluation Budget.

R&D: Abbreviation for RDT&E.

RTS: Rate of Technical Substitution.

SAR: System Acquisition Reports.

APPENDIX A

APPENDIX A

DATA AND DATA ADJUSTMENTS

A.1 General Comments

The empirical results of Chapter IV depend on the data and data adjustments of this appendix. In hypothesis 1, the relationships between cost growth g and program time t hinge on the more elementary data contained herein. Similarly, in hypothesis 2 the time series H/M, h/m, and (w/r)* depend on the raw data and its refinement in this appendix. Thus, while the theoretical points of Chapter II and the model of Chapter III can stand on their own, the results of Chapter IV and the conclusions of Chapter V are valid only to the degree that they are not sensitive to inaccuracies in the data which are derived here.

Two things are accomplished in this appendix. The first is to present the pertinent raw data. The second is to transform the raw data into useful forms. The transformation procedures are completely described in the content notes of the tables and/or in the comments preceding the tables. The raw data is obtained from several sources, the principal of which are the following. The asset value of Navy property is obtained from the Federal Real and Personal Property Inventory Report published biennially in the prints of the House Committee on Government Operations [66]. The annual

fund flows which ultimately comprise Navy assets are based on the annual Budget of the U. S. Government [60]. Price indices are obtained from the Survey of Current Business [69] and associated Commerce Department publications. Most of the remaining sources are miscellaneous Department of Defense publications. The source notes to the tables are specific regarding raw data sources.

Some of the tables to follow should prove useful, in their own right, to other researchers. The ratio of manpower on board versus that required (Table 30) proved to be an illusive series. The fraction of Navy ships which are active (Table 15), and the average ship age (Table 16) are also not widely held data. These represent data elements which planners, when questioned, usually stated to be unavailable. Yet the interpretations of Defense efficiency, mentioned in Chapter I, are implicitly dependent on such data. The fact that Naval ships account for more than 30% of teh total DoD acquisitions in weapons and equipment[73] make them an important factor even in overall DoD studies. It must follow that variations in the fraction of these ships which are active (and therefore require crews) is important. It is especially important since the active

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[73] See [75, pp. 4 and 73]. DoD weapons and equipment are stated at 113 billion dollars, Navy ships at 35 billion.

fraction ranges from 0.36 to 0.80 (see Table 14). Furthermore, the fact that average ship age varies from 10 years to 17.7 years (1956 to 1974 timeframe, Table 14) has important implications; for the DoD inventory values as stated in House Committee on Government Operations biennial reports [66], are based on acquisition costs rather than replacement costs. Any conversion from acquisition cost to either current or constant dollars should account for ship age.

The tables will be introduced, as necessary, by comments relevant to the present research. The amount of discussion will depend on the apparent sensitivity of the results to the data under consideration. Data felt to be tenuous will be so indicated.

A.2 Comments on Data and Data Sources

Several important issues relating to Defense asset eavluation are implicit in the appendix tables and therefore in the research. The discussion will be aided if the relative magnitudes of the Navy budget categories included in the U.S. Budget are kept in mind. Table 7 provides the budget categories and their respective outlays for 1973 and 1963. These sample years will suit present purposes.

Two major budget categories in the table and their treatment pertain to the investigation of hypothesis 2. The first concerns the "O & M" budgets, the second the "RDT&E"

TABLE 7 -- Relative Budget Sizes of Navy Expenditures as Represented by Fiscal 1973 & 1963 Outlays (Billions of Dollars)

Budget Category	Outlays	
U.S. Navy Only:	1973	1963
Military Personnel (MILPERS)		
Navy	5.390	2.714
Navy Reserve	0.220	0.079
Operations and Maintenance (O&M)		
Navy	5.196	2.864
Navy Reserve	0.114	--
Procurement		
Aircraft and Missiles	3.181	3.230
Shipbuilding/Conversion	1.982	2.770
Other	1.665	0.890
Research, Dev., Test, Eval (RDT&E)	2.404	1.530
Military Construction		
Navy	0.383	0.190
Navy Reserve	0.011	0.006
Entire Defense Department:		
Retired Military Personnel	4.390	1.015
Family Housing	0.729	0.427

SOURCES: Executive Office of the President of the United States, The Budget of the United States, 1975 and The Budget of the United States 1965. (Washington, D.C.: Government Printing Office), Part 5.

budget. The Federal Real and Personal Property Inventory Reports do not explicitly include either of these budget categories in the appraisal of Defense property. In fact, the DoD inventory evolves only from the accumulated procurement and Construction budgets as these specify the sum of acquisition costs of systems obtained. Since the present research relies heavily on these reports, the treatment of the O & M and RDT&E budgets is important.

An implicit assumption of the research is that the O & M budgets are used to maintain systems in their original condition. Thus, O & M funds offset physical depreciation. By assuming this, the practice of appraising systems at their acquisition cost becomes a valid procedure--so long as these acquisition values are converted to constant dollars. While not stated explicitly, the inventory value of DoD property as shown in the Congressional reports must include this same assumption to have meaning, for depreciation does not enter the reports.

While O & M expenditures are implicitly reflected in the appraisal of defense systems and therefore in the research results, RDT&E funds are not. Neither the Federal Real and Personal Property Inventory Reports (hereafter called PPR's) nor the present research, include RDT&E expenditures explicitly. In the case of the research, this is because R & D expenditures are not only impossible to

realistically attribute to hardware systems, but they often cannot even be attributed to a timeframe. That is, it is virtually impossible to assign year t_i expenditures to year t_j system delivery.

While not completely satisfactory, RDT&E expenditures can be arbitrarily assumed to affect technical progress and, as was offered in Chapter V, to affect the bias of technical progress through factor price inducement. However, for the purposes of this appendix, it is only important to remember that the tables presented do not include RDT&E expenditures. Table 8 is provided to give some indication of the relative sizes of RDT&E and O&M budgets versus Procurement budgets.

As another item, Military Construction budgets are abstracted from the research. This can be justified for two reasons. First, military construction applies to structures relatively permanent compared to the 20 year time frame considered. This makes construction resemble a fixed cost which would not affect the results significantly. Second, construction is a relatively small budget category. This would imply that the research results are not sensitive to changes in construction budgets within the range of interest.

Some comments on the categorization of data in terms of Navy vs. Marine Corps, and in terms of the hardware categories are appropriate. The Navy was chosen as the service of interest partly because it is least susceptible to large man-

TABLE 8 -- Operations and Maintenance (O&M) and Research, Development, Test and Evaluation (RDT&E) Expenditures for Selected Years (Billions of Current Dollars)

Fiscal Year	O&M (1)	RDT&E (2)	Procurement (3)
1957	2.45	0.52	3.41
8	2.57	0.62	4.35
9	2.61	0.80	3.53
1960	2.59	0.77	3.68
1	2.69	1.19	4.55
2	2.87	1.30	5.07
3	2.86	1.43	6.40
4	2.89	1.58	5.73
1965	3.17	1.29	4.78
6	3.79	1.41	5.08
7	4.68	1.79	6.07
8	4.73	2.00	7.20
9	5.34	2.05	7.74
1970	5.11	2.08	7.35
1	5.07	2.40	6.95
2	5.31	2.43	6.99
3	5.20	2.40	6.81
4	(5.96)	(2.57)	(6.98)

SOURCES: Executive Office of the President of the United States, The Budget of the United States (Washington, D.C.: Government Printing Office, Annual). Part 5.

power fluctuations during war periods. While the Navy principally continues its missions at sea during conflicts, and must do so largely with the systems it has when conflicts begin, the Marine Corps has huge fluctuations in ground forces between peace and war. These fluctuations would tend to distort the hardware/manpower ratios in the Navy Department (which includes both the Navy and Marine Corps) since ships, for example, would remain relatively constant. Abstracting the Marine Corps from the PPR's (Personal Property Reports), which combine the two services in most categories, is therefore essential. The inaccuracies resulting from attempts to allocate asset categories to the Navy or Marine Corps are considered less serious than the confounding effects of including both services in the analysis. The asset categories used necessarily match those provided in the PPR's—the only comprehensive source of data available publicly on Defense asset values by any measure.

A summary of the aims of the appendix based on the above can be provided. The data relating to undercosting of manpower and hardware (hypothesis 1) is discussed in Chapter IV, and the data presented here is straightforward. The data on hypothesis 2 in its raw form is not suitable to the needs of the research and needs conversion. The hardware valuations are based on acquisition cost in current dollars and combine Navy and Marine Corps assets. In this appendix the

valuations are converted to replacement costs at constant dollars with the Marine Corps extracted. The manpower levels in raw form are available in actual on-hand manpower. These must be converted to estimates for manpower implicitly re-quired by the weapon systems on hand.

A.3 Notational Comments Applying to All Tables

-- Data elements which were not available in the course of the research, but which could be reasonably estimated either from interpolations, trends, or other means are enclosed in parentheses when presented in the table proper. Thus, the 1968 element below is estimated while the 1967 and 1969 entries are not:

1967	31.3
1968	(32.4)
1969	33.5

-- Data elements which were not available and which either could not be reasonably estimated or did not need to be estimated for the research purposes are indicated by a double hyphen. Thus the 1955 element below was not available:

1955	--
1956	3.2
1957	9.1

-- All table entries are rounded to the number of digits shown. However, calculations are made prior to rounding. Therefore, arithmetic operations specified in the table notes, such as column summing or multiplying, may not exactly yield the results shown.

A.4 Tables and Comments Specific to Tables

Comments on Table 9:

The price index "hardware average," column (4), is an average of the Durable Goods index and the Machinery & Equipment index. Ships, service craft, and plant equipment costs seem more likely to follow the (wholesale) Machinery and Equipment index while avionics, supplies, and other equipments seem more properly associated with the Durable Goods index. The aggregate index is therefore obtained by weighting the Durable Goods index with the sum of columns (2) and (4) of Table 13, and the Machinery & Equipment index by the sum of columns (1) and (3) of the same table.

TABLE 9 -- Price Indices for Selected Categories of Goods Related to Defense Procurement and Compensation (1967 = 100)

Fiscal Year	Compensation (1)	Durable Goods (2)	Mach & Equip. (3)	Hardware Average (4)	(w/r)* (1)÷(4) (5)
1955	71.8	82.8	75.7	79.3	.89
6	74.2	88.3	81.8	85.0	.845
7	74.3	91.2	87.6	89.4	.83
8	75.6	92.1	89.4	90.8	.83
9	79.5	94.2	91.3	92.6	.86
1960	79.5	94.2	92.0	92.8	.86
1	81.3	93.7	91.9	92.5	.88
2	81.3	93.4	92.0	92.5	.88
3	82.1	93.4	92.2	92.7	.89
4	87.6	94.7	92.8	93.5	.94
1965	91.3	95.9	93.9	94.6	.96
6	96.1	98.1	96.8	97.2	.99
7	100.0	100.0	100.0	100.0	1.00
8	103.8	103.4	103.2	103.3	1.00
9	110.2	107.9	106.5	107.0	1.03
1970	123.6	112.4	111.4	111.7	1.11
1	131.4	117.0	115.5	116.0	1.13
2	148.6	121.1	117.9	119.1	1.25
3	165.8	127.9	121.7	124.1	1.34
4	(192.0)	150.0	137.2	142.1	1.36

SOURCES: Columns (2) and (3) from U.S. Department of Commerce, Bureau of Economic Analysis, Business Statistics; The Biennial Supplement to the Survey of Current Business (Washington, D.C.: Government Printing Office, September 1973), pp. 44-49 for 1950 thru 1972. 1973 and on from Survey of Current Business, December 1974, Table 5-8.

Column (1) is column (4) of Table 10 converted to 1967=100 base.

Column (4) is a weighted average of columns (2) and (3).

(w/r)* represents the ratio of price indices in year t to those in year 1967, ie, $(w/r)^* = (w/r)_t/(w/r)_{1967}$. See equation (11).

Comments on Table 10:

Since approximately one-third of the personnel costs in DoD are for civilians, then any attempt to isolate manpower costs from hardware costs must include civilian as well as military manpower. The overall pay index weights the military and civilian indices by the relative numbers of each employed.

Regular military compensation is directly available in the table's source from 1964 on. Prior to 1964 only base pay indices are available for military personnel. The source states, however, that a 4% rise in base pay equates very closely to a 3% rise in military compensation because fringe benefits, which amount to approximately 30% of compensation, have changed more slowly than base pay. The note to the table specified how the pre-1964 data is converted to compensation data.

TABLE 10 -- Military, Civilian and Overall Defense Pay Indices for Selected Years (1964 = 100)

Fiscal Year	Regular Military Compensation (1)	Classified Civilian Salaries (2)	Fraction Civilian (3)	Overall Compensation Index (4)
1955	83.4	74.7	0.325	80.6
6	87.7	78.4	0.320	84.7
7	87.7	78.4	0.315	84.8
8	88.1	82.3	0.315	86.3
9	92.8	86.3	0.310	90.8
1960	92.8	86.3	0.305	90.8
1	92.8	92.9	0.300	92.8
2	92.8	92.9	0.290	92.9
3	92.8	96.5	0.285	93.8
4	100.0	100.0	0.280	100.0
1965	103.6	106.3	0.275	104.3
6	101.1	109.2	0.275	109.8
7	114.5	113.3	0.280	114.2
8	119.2	117.1	0.280	118.6
9	126.4	124.2	0.285	125.8
1970	141.9	139.6	0.290	141.2
1	151.0	147.9	0.300	150.1
2	175.5	156.4	0.305	169.7
3	200.6	164.5	0.300	189.4
4				

SOURCE: U.S. Department of Defense (Comptroller), The Economics of Defense Spending A Look at the Realities (Washington, D.C.: Government Printing Office, July 1972), Tables 15-3 and 15-4.

NOTES: Column (1) figures prior to 1964 derived from source, table 15-3 using formula 100-3/4(100-i(t)); where i(t) is military pay index from that table.

Column (4) is average of columns (1) and (2), weighted by ratios of civilian and military personnel as reflected in column (3).

Comments on Table 11:

The series $(h/m)_t$ is presented, and is estimated by an empirical mutation of equation (10) of Chapter III (section III.2.3). In that expression the bracketed term $[H_t(1-\delta)+R_t]$ is the hardware in stock in period t which is carried forward to period t+1. Calling this amount H^*_{t+1}, and realizing that the amount of old hardware carried forward to t+1 must equal the total amount on hand at the end of t+1 less the new hardware obtained during t+1, it follows that $H^*_{t+1} = H_{t+1} - h^*_t$, where h^*_t is new equipment, approximated by total procurement expenditures in period t. Alternatively, $H^*_t = H_t - h^*_{t-1}$. Equation (10) then can be written

$$(h/m)_{t-1} = \frac{(H/M)_t H_t - (H/M)_{t-1} H^*_t}{h^*_{t-1}} \quad . \tag{10"}$$

Each of these quantities is included in the table. h^*_{t-1} is obtained i.. Table 12 and derives from procurement budgets in the U.S. Budget. The following diagram may be helpful.

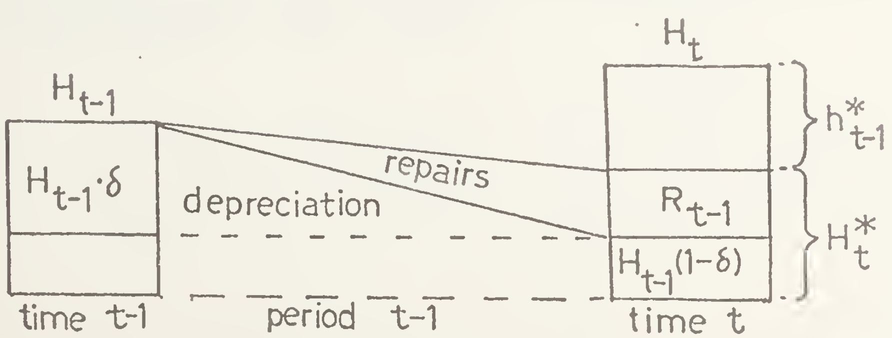

TABLE 11 -- Determination of Imputed Incremental Hardware-to-Manpower Ratio h/m (Dollar Figures in Millions of 1967 Dollars)

Fiscal Year	$(H/M)_t$ (1)	H_t (2)	h^*_{t-1} (3)	$H^*_t=H_t-h^*_{t-1}$ (4)	$(h/m)^*_{t-1}$ (5)
1955	(45.17)	(44.40)	3.54	--	--
6	44.87	43.30	3.59	39.71	41.55
7	42.25	40.73	3.79	36.94	16.71
8	39.78	38.83	4.78	34.05	22.19
9	39.85	38.02	3.78	34.24	40.48
1960	44.95	42.07	3.94	38.13	94.31
1	47.35	44.27	4.90	39.37	66.63
2	50.49	49.28	5.40	43.88	76.01
3	53.88	52.32	6.89	45.43	76.23
4	55.18	54.68	6.10	48.58	65.53
1965	56.88	55.69	5.02	50.67	74.01
6	54.41	58.06	5.20	52.86	29.30
7	55.47	61.74	6.08	55.66	65.17
8	58.30	63.31	6.96	56.35	81.21
9	57.12	61.52	7.20	54.32	48.22
1970	60.21	58.22	6.55	51.67	84.59
1	63.61	56.36	5.97	50.39	92.31
2	62.99	53.67	5.82	47.85	57.89
3	62.67	52.64	5.42	47.22	59.88
4	61.98	51.13	4.78	46.35	55.29

NOTES: Column (1) is the same as column (1) of Table 5 and column (2) is from Table 13. Column (3) is derived in Table 12. Column (5) is obtained as explained in the text immediately preceding this table.

TABLE 12 -- U. S. Navy Major Procurement Expenditures by Fiscal Year in Current and in 1967 Dollars (Billions of Dollars)

Fiscal Year	Aircraft/Missiles Current $	Aircraft/Missiles 1967 $	Shipbuilding/ Conversion Current $	Shipbuilding/ Conversion 1967 $	Ordnance & Ammo/ Other Current $	Ordnance & Ammo/ Other 1967 $	h^*_{t-1}=Total Expended 1967 $
1955	1.19	1.43	0.899	1.19	0.760	0.92	3.54
6	1.78	2.02	0.933	1.1[illegible]	0.380	0.43	3.59
7	2.172	2.38	0.933	1.07	0.309	0.34	3.79
8	2.510	2.73	1.515	1.69	0.328	0.36	4.78
9	1.980	2.10	1.280	1.40	0.265	0.28	3.78
1960	2.027	2.15	1.360	1.48	0.290	0.31	3.94
1	2.069	2.21	1.908	2.08	0.572	0.61	4.90
2	2.603	2.79	1.962	2.07	0.506	0.54	5.40
3	3.018	3.23	2.551	2.77	0.827	0.89	6.89
4	2.758	2.91	2.087	2.25	0.889	0.94	6.10
1965	2.235	2.33	1.717	1.83	0.826	0.86	5.02
6	2.520	2.57	1.480	1.53	1.075	1.10	5.20
7	3.006	3.01	1.398	1.40	1.668	1.67	6.08
8	3.642	3.52	1.356	1.31	2.206	2.13	6.96
9	3.315	3.07	1.949	1.83	2.478	2.30	7.20
1970	3.183	2.83	2.066	1.85	2.097	1.87	6.55
1	2.913	2.49	2.114	1.83	1.925	1.65	5.97
2	3.176	2.62	1.978	1.68	1.839	1.53	5.82
3	3.181	2.49	1.982	1.63	1.665	1.30	5.42
4	(3.310)	(2.21)	(2.020)	(1.47)	(1.647)	1.10	4.78

SOURCE: The Budget of the United States Government - Appendix (1957 through 1975. 1974 figures are estimated in 1975 budget. Dollar conversion factors are column (3) Table 9 for Shipbuilding, and column (2) Table 9 for remainder.

Comments on Table 13:

Data for the table was not available for fiscal 1955. Consequently H_t for 1955 was obtained by multiplying the 1956 H_t entry by the ratio of Capital Stock in 1955 to that in 1956, as determined in a Rand report [86, first unnumbered table]. The values were 186.0 and 181.4 respectively, yielding the 44.4 figure here.

TABLE 13 -- Estimated Total Property Value of U.S. Navy Hardware (Billions of 1967 Dollars)

Fiscal Year	Ships	Aircraft/ Missiles	Svce Craft & Plant Equip.	Supplies & Other Equip.	Total (H_t)
1955	--	--	--	--	(44.4)
6	15.3	3.67	7.0	17.3	43.3
7	14.4	3.55	6.37	16.4	40.7
8	14.5	3.94	(5.76)	(14.6)	(38.8)
9	15.7	4.01	5.39	12.9	38.0
1960	20.9	3.97	5.55	11.6	42.1
1	24.1	4.06	4.82	11.3	44.3
2	27.6	4.72	(4.76)	(12.2)	(49.3)
3	28.5	5.93	4.65	13.2	52.3
4	30.6	6.32	4.99	12.8	54.7
1965	31.9	7.31	(4.48)	(12.0)	(55.7)
6	35.3	7.32	4.18	11.3	58.1
7	38.1	7.80	(4.14)	(11.7)	(61.7)
8	38.3	8.72	4.28	12.0	63.3
9	36.3	9.46	(4.26)	(11.5)	(61.5)
1970	31.9	10.83	4.42	11.1	58.2
1	30.6	11.01	(4.65)	(10.1)	(56.4)
2	28.9	10.6	4.95	9.22	53.7
3	27.8	11.0	(4.88)	(8.96)	(52.6)
4	26.7	10.9	4.83	8.70	51.1

NOTES: 1955 total based on relative size of 1955 to 1956 capital stock ratio in [86] times 1956 value above. Column (1) is from Table 14, column (2) from Table 17, column (3) from Table 20, and column (4) from Table 22.

Comments on Table 14:

Ships represent the largest fraction of Defense property. Their appraised value is therefore important. From the standpoint of hardware/manpower ratios, inactive ships (those in "mothballs") should be excluded from the analysis. The appraised value of the inventory should furthermore represent a replacement cost. Applying the price index for the year of ship acquisition rather than the year of appraisal, and applying this only to the active ships, yields a reasonable proxy for a measure of ship value in 1967 terms. The assumption that O & M funds maintain the active ships in original condition is basic to the 1967 evaluation.

TABLE 14 -- Estimated Property Value of All U. S. Navy Ships (Columns (1) and (5) in Billions of Dollars)

Fiscal Year	Acquisition Cost (1)	Fraction Active (2)	Ship Age (Years) (3)	Index (4)	Value in 1967 $ (5)
1956	19.8	0.36	10.0	46.5	15.3
7	20.5	0.36	10.2	51.3	14.4
8	21.8	0.37	10.6	55.5	14.5
9	21.5	0.43	10.9	58.7	15.8
1960	22.1	0.53	12.5	55.9	20.9
1	22.6	0.62	13.0	58.2	24.1
2	23.3	0.69	14.0	58.2	27.6
3	24.5	0.69	14.6	59.3	28.5
4	26.3	0.70	15.3	60.2	30.6
1965	27.7	0.71	15.7	61.6	31.9
6	29.1	0.75	16.6	61.8	35.3
7	30.0	0.79	17.4	62.2	38.1
8	31.3	0.80	17.7	65.3	38.3
9	32.0	0.80	17.7	70.6	36.3
1970	32.2	0.71	17.4	71.6	31.9
1	33.9	0.66	17.2	73.0	30.6
2	34.7	0.64	16.8	76.9	28.9
3	35.1	0.68	16.3	85.9	27.8
4	35.3	(0.68)	15.7	90.0	26.7

NOTES: Column (1) is from Table 25, column (2) is R_t from Table 15, column (3) is from Table 16.

Index (column (4)) is the price index relative to 1967 for wholesale machinery and equipment for the year of acquisition for the average ship. Thus if ship age is A in year t, then index is for year t-A from tables 5-8 of the Survey of Current Business [69].

Column (5) is obtained by multiplying (1) by (2), and converting product to 1967 terms through index of column (4).

Comments on Table 15:

The purpose of the table is to yield R_t, the "Fraction Active" of all ships for year t. If the total replacement cost in year t of all ships (active and inactive) is Σnw, then $R_t \Sigma nw$ represents the replacement cost in year t of the active ships. The weighting factor w for each ship type mainly is based on relative ship tonnage, but has an adjustment based on building cost. This adjustment reflects the author's estimates of relative building cost per ship-ton of the various types. Thus a submarine of the same tonnage as a surface ship may cost twice as much to build due to the extra costs of submergence capabilities. The w's are meant to be representative of the broad spectrum of ship classes within each ship type. They are therefore relatively crude, but considered adequate for the overall sensitivity inherent in R_t.

TABLE 15 -- Data on U. S. Navy Ships by Number of Each Type (n), Relative Value of Ship Type (w), Fraction Active (r) for Period 1956-1973

Ship Type	(w)	Year (n/nw/r/nwr) 1956	1957	1958
Carrier	(50)	(073/3650/.33/1204)	(073/3650/.30/1095)	(072/3600/.33/1108)
Battleship	(45)	(015/0675/.20/0135)	(016/0720/.13/0094)	(015/0675/0.0/0000)
Cruiser	(10)	(072/0720/.22/0158)	(067/0670/.24/0161)	(066/0660/.23/0152)
Destroyer	(2.5)	(368/0920/.68/0626)	(368/0920/.69/0635)	(371/0928/.66/0612)
Escort	(1.5)	(340/0510/.24/0122)	(203/0305/.47/0143)	(334/0501/.25/0125)
Submarine	(5)	(169/0845/.65/0549)	(162/0810/.71/0575)	(160/0800/.69/0536)
Amphibious	(8)	(577/4616/.24/1108)	(539/4312/.25/1078)	(413/3304/.29/0958)
Mine Warfare	(0.8)	(265/0212/.43/0091)	(269/0215/.39/0084)	(267/0214/.29/0062)
Auxiliary	(7)	(508/3556/.46/1652)	(496/3472/.45/1562)	(478/3346/.45/1505)
Command Ship	(10)	(001/0010/1.0/0010)	(001/0010/1.0/0010)	(001/0010/1.0/0010)
($\Sigma nw/\Sigma nwr/R_t$)		(15714/5656/0.36)	(15083/5437/0.36)	(14037/5149/0.37)

Source and content notes at end of table.

(Continued)

TABLE 15 -- (Continued)

Ship Type	(w)	Year (n/nw/r/nwr) 1959	1960	1961
Carrier	(50)	(055/2750/.43/1182)	(024/1200/.96/1152)	(024/1200/1.0/1200)
Battleship	(45)	(010/0450/0.0/0000)	(008/0360/0.0/0000)	(008/0360/0.0/0000)
Cruiser	(10)	(042/0420/.29/0122)	(040/0400/.33/0132)	(042/0420/.29/0122)
Destroyer	(2.5)	(351/0878/.68/0597)	(349/0874/.65/0567)	(343/0858/.65/0588)
Escort	(1.5)	(291/0437/.24/0105)	(288/0432/.40/0173)	(253/0380/.19/0072)
Submarine	(5)	(151/0755/.75/0566)	(131/0655/.86/0563)	(130/0650/.88/0572)
Amphibious	(8)	(326/2608/.37/0965)	(286/2288/.40/0915)	(227/1816/.50/0908)
Mine Warfare	(0.8)	(266/0213/.31/0066)	(196/0157/.41/0064)	(192/0154/.46/0071)
Auxiliary	(7)	(480/3360/.43/1445)	(421/2947/.41/1384)	(413/2891/.66/1908)
Command Ship	(10)	(001/0010/1.0/0010)	(001/0010/1.0/0010)	(001/0010/1.0/0010)
($\Sigma nw/\Sigma nwr/R_t$)		(11880/5057/0.43)	(09321/4963/0.53)	(08739/5420/0.62)

Source and content notes at end of table.

(Continued)

TABLE 15 -- (Continued)

Ship Type	(w)	Year (n/nw/r/nwr) 1962	1963	1964
Carrier	(50)	(026/1300/1.0/1300)	(025/1250/.96/1200)	(025/1250/.96/1200)
Battleship	(45)	(004/0180/0.0/0000)	(004/0180/0.0/0000)	(004/0180/0.0/0000)
Cruiser	(10)	(039/0390/.33/0130)	(039/0390/.36/0140)	(040/0400/.35/0140)
Destroyer	(2.5)	(360/0900/.67/0603)	(343/0855/.66/0564)	(254/0381/.18/0069)
Escort	(1.5)	(280/0420/.26/0109)	(253/0380/.18/0066)	(129/0645/.97/0626)
Submarine	(5)	(132/0660/.89/0587)	(122/0610/.98/0598)	(254/0102/.18/0018)
Amphibious	(8)	(234/1872/.57/1067)	(234/1872/.57/1067)	(223/1784/.60/1070)
Mine Warfare	(0.8)	(169/0135/.53/0072)	(165/0132/.53/0070)	(158/0126/.54/0068)
Auxiliary	(7)	(348/2436/.76/1851)	(333/2331/.79/1841)	(331/2317/.79/1830)
Command Ship	(10)	(001/0010/1.0/0010)	(002/0020/1.0/0020)	(002/0020/1.0/0020)
($\Sigma nw/\Sigma nwr/R_t$)		(8303/5729/.69)	(8019/5568/0.69)	(7988/5589/0.70)

Source and content notes at end of table.

(Continued)

TABLE 15 -- (Continued)

Ship Type	(w)	Year (n/nw/r/nwr) 1965	1966	1967
Carrier	(50)	(026/1300/.96/1248)	(025/1250/.92/1150)	(025/1250/.92/1150)
Battleship	(45)	(004/0180/0.0/0000)	(004/0180/0.0/0000)	(004/0180/0.0/0000)
Cruiser	(10)	(039/0390/.36/0140)	(035/0350/.40/0140)	(034/0340/.38/0129)
Destroyer	(2.5)	(367/0918/.64/0588)	(359/0898/.65/0584)	(358/0895/.66/0591)
Escort	(1.5)	(254/0381/.18/0069)	(232/0348/.20/0070)	(229/0343/.23/0079)
Submarine	(5)	(136/0680/.99/0673)	(143/0715/.99/0708)	(148/0740/.99/0733)
Amphibious	(8)	(217/1736/.62/1076)	(205/1640/.78/1279)	(180/1440/.90/1296)
Mine Warfare	(0.8)	(153/0122/.56/0068)	(150/0120/.56/0067)	(127/0102/.65/0066)
Auxiliary	(7)	(329/2303/.80/1842)	(307/2149/.80/1719)	(302/2114/.84/1776)
Command Ship	(10)	(002/0020/1.0/0020)	(002/0020/1.0/0020)	(002/0020/1.0/0020)
$(\Sigma nw/\Sigma nwr/R_t)$		(8029/5725/0.71)	(7670/5737/0.75)	(7423/5840/0.79)

Source and content notes at end of table.

(Continued)

TABLE 15 -- (Continued)

Ship Type	(w)	Year (n/nw/r/nwr) 1968	1969	1970
Carrier	(50)	(025/1250/.92/1150)	(025/1250/.88/1100)	(025/1250/.76/0950)
Battleship	(45)	(004/0180/.25/0045)	(004/0180/.25/0045)	(004/0180/0.0/0000)
Cruiser	(10)	(034/0340/.38/0129)	(034/0340/.38/0129)	(031/0310/.32/0099)
Destroyer	(2.5)	(343/0858/.70/0601)	(331/0828/.67/0555)	(301/0753/.58/0437)
Escort	(1.5)	(204/0306/.29/0089)	(181/0271/.29/0079)	(187/0284/.33/0094)
Submarine	(5)	(147/0735/.99/0728)	(144/0720/.99/0713)	(148/0740/.99/0733)
Amphibious	(8)	(175/1400/.90/1260)	(166/1328/.92/1222)	(121/0968/.80/0774)
Mine Warfare	(0.8)	(124/0099/.68/0067)	(114/0091/.65/0059)	(110/0088/.58/0051)
Auxiliary	(7)	(299/2093/.84/1758)	(288/2016/.85/1714)	(253/1771/.77/1364)
Command Ship	(10)	(002/0020/1.0/0020)	(002/0020/1.0/0020)	(002/0020/0.0/0000)
($\Sigma nw/\Sigma nwr/R_t$)		(7280/5847/0.80)	(7044/5636/0.80)	(6363/4501/0.71)

Source and content notes at end of table.

(Continued)

TABLE 15 -- (Continued)

Ship Type	(w)	Year (n/nw/r/nwr) 1971	1972	1973
Carrier	(50)	(025/1250/.72/0900)	(026/1300/.65/0845)	(025/1250/.64/0800)
Battleship	(45)	(004/0180/0.0/0000)	(004/0180/0.0/0000)	(004/0180/0.0/0000)
Cruiser	(10)	(021/0210/.43/0090)	(021/0210/.43/0090)	(021/0210/.43/0090)
Destroyer	(2.5)	(310/0775/.51/0395)	(259/0648/.58/0376)	(219/0548/.59/0323)
Escort	(1.5)	(185/0278/.40/0111)	(173/0260/.47/0122)	(110/0165/.74/0122)
Submarine	(5)	(149/0745/.95/0708)	(143/0715/.94/0672)	(134/0670/.94/0630)
Amphibious	(8)	(123/0984/.63/0620)	(122/0976/.63/0615)	(108/0864/.63/0544)
Mine Warfare	(0.8)	(088/0070/.48/0034)	(077/0062/.40/0025)	(033/0026/.48/0012)
Auxiliary	(7)	(245/1715/.73/1252)	(226/1582/.68/1076)	(190/1330/.78/1037)
Command Ship	(10)	(002/0020/0.0/0000)	(002/0020/0.0/0000)	(002/0020/0.0/0000)
($\Sigma nw/\Sigma nwr/R_t$)		(6227/4110/0.66)	(5953/3821/0.64)	(5262/3559/0.68)

SOURCES: Active and Inactive units by ship type from unpublished data provided by Director of (U.S.) Naval History, Washington, D.C., March 26, 1975. Original data verbally credited to Samuel L. Morison by representative of Director of Naval History. Compilation apparently based on [44] as well as earlier editions.

NOTES: n is number of units active. r is ratio of active units to total units in class. w is relative weight of ship type in value terms, and is a combination of displacement of ship and estimated quality adjustment based on author's estimates. R_t is $\Sigma nwr \div \Sigma nw$, and represents estimated fraction active in terms of replacement cost.

Comments on Table 16:

The data is based on evidence provided in 1965 by Admiral E. P. Holmes to the Congress in his capacity as Commander in Chief, U.S. Atlantic Fleet. It represents data accumulated on Atlantic Fleet ships only, with ships unweighted by size or value. It is also based on the time the ship was built, and does not account for new equipments installed since ship commissioning.

The assumption is made in the present research that the ages of Atlantic Fleet ships are representative of the entire U.S. Navy, that the unweighted age average is representative of the true average age, and that ship improvements have been negligible compared to initial procurement cost when compared in constant dollars.

TABLE 16 -- Estimated Average Age of U.S. Naval Ships in Years as of End of Fiscal Years

Fiscal Year	Average Age	Fiscal Year	Average Age
1950	5.5	1965	15.7
1	6.3	6	16.6
2	7.1	7	17.4
3	8.6	8	17.7
4	8.9	9	17.7
1955	9.5	1970	(17.4)
6	10.0	1	(17.2)
7	10.2	2	(16.8)
8	10.6	3	(16.3)
9	10.9	4	(15.7)
1960	12.5	1977	(12.7)
1	13.0		
2	14.0	1980	11.4
3	14.6		
4	15.3	1985	12.9

SOURCE NOTES: For 1950-64, source is U.S. Congress, House, Status of Naval Ships. Hearings Before the Special Committee on Sea Power of the Committee on Armed Services [65].

For 1980 and 1984, source is Department of Defense, "Secretary of Defense James A. Schlesinger Annual Defense Department Report FY 1965" [71].

1970-74 and 1977 are linear interpolations between 1969 data and 1980 estimate.

TABLE 17 -- Estimated Property Value of Navy Aircraft, Aircraft Support Equipment, Missiles, and Ammunition not Accounted for in Navy Supply (Billions of Dollars)

Fiscal Year	Acquisition Cost (1)	Fraction Active (2)	Index (t-5) (3)	Value in 1967 $ (4)
1956	3.3	(0.78)	70.2	3.67
7	3.5	(0.78)	77.0	3.55
8	3.9	(0.78)	77.3	3.94
9	4.0	0.79	78.8	4.01
1960	4.0	0.79	79.6	3.97
1	4.2	(0.80)	82.8	4.06
2	5.15	(0.81)	88.3	4.72
3	6.6	(0.82)	91.2	5.93
4	7.1	(0.83)	91.1	6.32
1965	8.3	0.83	94.2	7.31
6	8.1	(0.85)	94.1	7.32
7	8.3	(0.88)	93.7	7.80
8	8.95	0.91	93.4	8.72
9	9.5	0.93	93.4	9.46
1970	11.14	0.92	94.7	10.83
1	(12.0)	0.88	95.9	11.01
2	12.1	0.86	98.1	10.06
3	(12.35)	0.89	100.0	11.0
4	12.45	(0.89)	101.7	10.9

NOTES: Column (1) is from column (5) of Table 24. Column (2) is from Table 18.

The average age of Navy tactical aircraft in 1975 is approximately 5.3 years [71, p. 219]. Because of aircraft turnover rates, a 5 year average age is assumed throughout, thus the index used to convert assets held year t to 1967 equivalents, is the index for year t-5. The durable goods index from Table 9 is used, extended to include pre-1955 dates.

The fraction active by number of aircraft in Table 18 is assumed to be equal to the fraction active by normalized acquisition cost in this table.

TABLE 18 -- Navy and Marine Corps Combined Total Aircraft, Selected Years

Fiscal Year	Total Active (1)	Total Inactive (2)	Ratio of Active to Total Aircraft (3)
1955	12,763	3,677	0.78
6	--	--	(0.78)
7	--	--	(0.78)
8	--	--	(0.78)
9	--	--	(0.79)
1960	8,848	2,406	0.79
1	--	--	(0.80)
2	--	--	(0.81)
3	--	--	(0.82)
4	--	--	(0.82)
1965	8,002	1,668	0.83
6	--	--	(0.85)
7	--	--	(0.88)
8	8,448	834	0.91
9	8,468	680	0.93
1970	7,893	717	0.92
1	7,299	966	0.88
2	6,732	1,084	0.86
3	6,716	857	0.89
4	--	--	(0.89)

SOURCE: U.S. Department of Commerce, Bureau of the Census, Statistical Abstract of the United States: 1974, (95th Edition) (Washington, D.C.: Government Printing Office, 1974), Table No. 506.

NOTE: The breakdwon of active vs. inactive aircraft has not been available from other sources, and earlier editions of the source document contaon no such data for the missing years. The source references U.S. Department of Defense, Office of the Secretary, unpublished data as the base source.

TABLE 19 -- Estimated Fraction of Combined Navy and Marine Corps Tactical Aircraft Belonging to Navy Only, by Weight of Aircraft Totals

	Selected Years	Navy Fraction
Prior	1961	0.65 (estimated)
	1961	0.66
	1964	0.68
	1968	0.62
	1972	0.70
	1974	0.70

SOURCE: William D. White, U.S. Tactical Air power. Missions, Forces, and Costs, (Washington, D.C.: Brookings Institution, [1974], p. 18, table 3-3.

The data collected in the source are specifically for tactical aircraft. The present research assumes the ratios for tactical aircraft are representative of all aircraft.

TABLE 20 -- Estimated Property Value of Service Craft and Plant Equipment in U.S. Navy, Conversion to 1967 Dollars (Billions)

Fiscal Year	Plant Equip. (1)	Service Craft (2)	Total (3)	Index (t-10) (4)	Est. Value in 1967 $ (5)
1956	2.26	1.0	3.26	46.5	7.01
7	2.42	1.0	33.42	53.7	6.37
8	(2.37)	(0.98)	(3.35)	58.2	(5.76)
9	2.32	0.97	3.29	61.0	5.39
1960	2.54	0.96	3.50	63.1	5.55
1	2.47	0.93	3.40	70.5	4.82
2	(2.47)	0.89	(3.36)	70.6	(4.76)
3	2.48	0.88	3.36	72.2	4.65
4	2.46	1.20	3.66	73.4	4.99
1965	(2.49)	0.90	(3.39)	75.7	(4.48)
6	2.52	0.90	3.42	81.8	4.18
7	(2.72)	0.91	(3.63)	87.6	(4.14)
8	2.92	0.91	3.83	89.4	4.28
9	(3.02)	0.87	(3.89)	91.3	(4.26)
1970	3.12	0.95	4.07	92.0	4.42
1	(3.29)	0.98	(4.27)	91.9	(4.65)
2	3.45	1.10	4.55	92.0	4.95
3	(3.46)	1.04	(4.50)	92.2	(4.88)
4	3.48	1.00	4.48	92.8	4.83

SOURCE NOTES: Columns (1) and (2) from Table 21 and column (2) of Table 25 respectively.

The "Service Craft" column of the table is obtained directly from the combined Navy and Marine Corps data of Table 25 since no adjustment to extract the Marine Corps from this category is considered necessary. The preponderance of service craft (tugs, lighters, etc.) in the Navy Department are Navy craft.

TABLE 21 -- Estimated Values of U.S. Navy Plant Equipment Exclusive of Marine Corps valued at Acquisition Cost (Billions of Dollars)

Fiscal Year	Navy Plant Equip.	Fiscal Year	Navy Plant Equip.
1955	--	1965	--
6	2.26	6	2.52
7	2.42	7	--
8	--	8	2.92
9	2.32	9	--
1960	2.54	1970	3.12
1	2.47	1	--
2	--	2	3.45
3	2.48	3	--
4	2.46	4	3.48

NOTE: Navy Plant Equipment is obtained by multiplying column (5) of Table 26 by corresponding element of Table 31.

Data isolating Navy and Marine Corp data on plant equipment is not available, and it must therefore be arbitrarily assigned. It was decided to utilize the ratio of Navy personnel to Marine Corps personnel to accomplish this.

TABLE 22 -- Estimated Value of Equipment and Supplies in U.S. Navy Supply System (Billions of Dollars)

Fiscal Year	Equip. & Supplies in Current $ (1)	Index (t-1) (2)	Value in 1967 $ (3)
1956	14.35	82.8	17.33
7	14.49	88.3	16.41
8	--	91.7	(14.6)
9	11.85	29.1	12.87
1960	10.97	94.2	11.65
1	10.67	94.1	11.29
2	--	93.7	(12.2)
3	12.37	93.4	13.24
4	11.93	93.4	12.77
1965	--	94.7	(12.0)
6	10.80	95.9	11.26
7	--	98.1	(11.7)
8	12.01	100.0	12.01
9	--	103.4	(11.5)
1970	11.94	107.9	(11.07)
1	--	112.4	(10.1)
2	11.16	117.0	9.54
3	--	121.1	(9.12)
4	11.13	127.9	8.70

NOTES: Column (1) is obtained from Table 23. Index is index for durable goods, Table 9. Assumption that goods in Supply System have average age of one year leads to using index for year t-1 instead of t to convert to 1967 dollars. The use of the one year average age is an arbitrary estimate.

TABLE 23 -- Navy Fraction of Total Annual Navy/Marine Corps Supply Assets (Dollars in Billions)

Fiscal Year	Navy Supplies ($) (1)	Marine Corps Supplies ($) (2)	Navy Fraction (1)÷((1)+(2)) (3)
1956	14.35	1.84	0.89
7	14.49	1.68	0.90
8	--	--	(0.89)
9	11.85	1.42	0.89
1960	10.97	1.49	0.88
1	10.62	1.86	0.85
2	--	--	(0.87)
3	12.37	1.42	0.90
4	11.93	1.51	0.89
1965	--	--	(0.89)
6	10.80	1.34	0.89
7	--	--	(0.88)
8	12.01	1.56	0.88
9	--	--	(0.87)
1970	11.94	2.12	0.85
1	--	--	(0.85)
2	11.16	2.11	0.84
3	--	--	(0.84)
4	11.13	2.19	0.84

SOURCE: U.S. Department of Defense, Office of the Assistant Secretary of Defense (Comptroller), Real and Personal Property of the Department of Defense (Annual), Part II, Section A.

Comment on Table 24:

The categories in the table are estimates for the Navy only portions of the corresponding categories of Table 25. The extraction of Marine Corps components is accomplished by assuming that the Navy fraction of these categories matches the Navy fraction of total assets held in the combined Navy and Marine Corps supply systems -- information which is directly available from the Federal Real and Personal Property Inventory Reports (PPRs).

The zero elements in columns (2), (3), and (4) result because early versions of the Real and Personal Property Reports accounted for these items elsewhere, principally under the "Equipment in Supply" or "Equipment Other than Production" categories (see, for example, Tables 25 and 26).

TABLE 24 -- Estimated Values of Selected U.S. Navy Seapon Peoperty Exclusive of Marine Corps, Valued at Acquisition Cost (Billions of Dollars)

Fiscal Year	Active & Inactive Aircraft (1)	Aircraft Support Equip. (2)	Missiles Not in Supply (3)	Ammo Not in Supply (4)	Total (5)
1956	3.3	0	0	0	3.3
7	3.5	0	0	0	3.5
8	3.9	0	0	0	3.9
9	4.0	0	0	0	4.0
1960	4.0	0	0	0	4.0
1	4.2	0	0	0	4.2
2	5.15	0	0	0	5.15
3	6.12	0.44	0.2	0	6.58
4	6.05	0.49	0.59	0	7.13
1965	7.14	0.51	0.66	0	8.31
6	6.63	0.51	0.97	0	8.11
7	6.88	0.51	0.93	0	8.32
8	7.32	0.52	0.80	0.31	8.95
9	7.50	0.51	0.87	0.61	9.49
1970	8.58	0.65	1.11	0.80	11.14
1	9.28	0.98	--	0.77	--
2	9.73	0.92	0.78	0.65	12.08
3	9.29	0.96	--	0.62	--
4	10.29	0.97	0.66	0.53	12.45

NOTES: Columns (1) and (2) obtained by multiplying columns (3) and (4) of Table 25 by nearest value from Table 19.

Columns (3) and (4) obtained by multiplying columns (4) and (5) of Table 25 by corresponding elements of Table 23.

Comments on Table 25:

The comment regarding zero elements made in the last table apply equally here. While the <u>Federal Real and Personal Property Inventory Reports</u> are not specific, it is apparent that "Equipment Other than Production" after 1960 was partly included in "Plant Equipment" (see Table 26) and partly to "Aircraft Support Equipment." These redesignations do not seriously effect the research results since in the aggregate, all categories are included, however redesignated.

The columns of Table 25 sum, within rounding error, to column (4) of Table 26, and represent weapons in use by the Navy at acquisition cost.

Column (4) of the table combines two categories in the source. These are there called "Spare Aircraft Engines" and "Ground Support Equipment."

TABLE 25 -- Categories of Weapon Property of the U.S. Navy Including Marine Corps Valued at Acquisition Cost (Billions of Dollars)

Fiscal Year	Active & Inactive Ships (1)	Service Craft (2)	Active & Inactive Aircraft (3)	Aircraft Support Equip. (4)	Missiles Support Supply (5)	Ammo not in Supply (6)	Marine Corps Equip. (7)	Equipment other than Production (8)
1956	19.8	1.0	5.0	0	0	0	--	1.6
7	20.5	1.0	5.3	0	0	0	--	1.8
8	21.8	--	5.9	0	0	0	--	--
9	21.5	0.97	6.1	0	0	0	--	1.8
1960	22.1	0.96	6.1	0	0	0	0.50	1.9
1	22.6	0.93	6.4	0	0	0	0.46	0
2	23.3	0.89	(7.8)	0	0	0	(0.49)	0
3	24.5	0.88	9.0	0.66	0.25	0	0.50	0
4	26.3	1.20	8.9	0.74	0.66	0	0.42	0
1965	27.7	0.90	10.5	0.78	0.74	0	0.63	0
6	29.1	0.90	10.2	0.78	1.10	0	0.85	0
7	30.0	0.91	11.1	0.83	1.06	0	1.99	0
8	31.3	0.91	11.8	0.84	0.91	0.35	1.02	0
9	32.0	0.87	12.1	0.83	1.00	0.70	1.24	0
1970	32.2	0.95	13.0	1.00	1.30	0.94	1.10	0
1	33.9	0.98	13.3	1.40	--	0.92	1.10	0
2	34.7	1.10	13.9	1.32	0.93	0.77	0.63	0
3	35.1	1.04	13.3	1.37	--	0.68	0.74	0
4	35.3	1.00	14.7	1.39	0.78	0.86	0.63	0

SOURCE NOTES: U.S. Congress, House, Committee on Government Operations, Federal Real and Personal Property Inventory Report, Committee Print (Washington, D.C.: Government Printing Office, biennial). See text for further explanations.

Comment on Table 26:

This table is presented to show the categories of assets contained in the <u>Federal Real and Personal Property Inventory Reports</u> (PPRs) and their respective magnitudes. When attempting to obtain hardware/manpower ratios of Defense Systems, it would be ideal to include all categories. However, all categories cannot be realistically included. Real property is excluded for several reasons. First, land can hardly be evaluated at replacement cost, nor does land effect in any measurable way the intrinsic hardware/manpower ratios of weapon systems. Buildings and facilities have a more direct effect, but one that again is not realistically measurable. For purposes of the present research, it seems more appropriate to treat such real property as fixed in time, and concentrate on the changes in hardware/manpower implicit in the more transitory components, namely weapon units.

Construction in progress is assumed to maintain the Real property at its necessary fixed level. The net result is that columns (1) and (2) of Table 26 are abstracted from the study. One can argue that under certain conditions, some buildings (such as aircraft hangers), cause changes in hardware/manpower ratios by making certain equipments unnecessary (e.g., the hangars allow using ordinary tools instead of expensive waterproof tools). It is assumed

in this research that such effects are negligible--especially since plant equipment is retained in the study and only the empty buildings are abstracted.

Industrial funds (column (6)) are excluded since they serve only as a transfer account, and furthermore are small in magnitude. Excess/surplus property is excluded from the hardware total since it is not manned. This treatment is similar to that given inactive ships. Finally, Disposed Ships (column (8)) are included in the active/inactive ship account in the PPR's. They are retained since they are ships in process of being dismantled, and therefore require manpower hours assumed commensurate with active units.

It should be stressed that the main property categories included in the study, i.e. columns (3) through (5), account for the preponderence of Defense assets. The research results should therefore not be overly degraded by the few required exceptions.

TABLE 26 -- Categories of Real and Personal Property of the U.S. Navy Including U.S. Marine Corps Valued at Acquisition Cost (Billions of Dollars)

Fiscal Year	Selected Real Property (1)	Construction in Progress (2)	Equip. in Supply System (3)	Weapons in Use (4)	Plant Equip. (5)	Industrial Funds (6)	Excess/ Surplus Property (7)	Disposed Ships (8)
1956	--	--	17.14	27.35	2.9	0.224	--	--
7	1.695	1.034	17.2	28.67	3.1	0.24	--	--
8	--	--	--	--	--	--	--	--
9	1.87	0.893	13.54	30.45	2.98	0.268	1.334	--
1960	2.035	0.643	12.7	31.6	3.26	0.226	1.62	--
1	2.132	0.663	12.44	30.31	3.17	0.913	1.23	--
2	--	--	--	--	--	--	--	--
3	2.079	1.09	13.79	35.79	3.18	0.191	1.04	--
4	2.085	0.533	13.44	38.31	3.16	0.167	1.52	0.13
1965	--	--	--	(41.2)	--	--	1.57	--
6	2.126	0.597	12.7	42.9	3.4	0.26	1.01	0.24
7	--	--	--	45.2	--	--	--	--
8	2.25	0.987	14.53	47.1	4.11	0.44	0.735	0.19
9	--	--	--	48.9	--	--	--	--
1970	2.24	1.10	14.95	50.9	4.27	0.32	1.194	0.634
1	--	--	--	52.4	--	--	--	--
2	2.30	0.60	14.4	53.4	4.6	0.40	1.60	1.00
3	--	--	--	--	--	--	--	--
4	2.40	1.476	14.54	54.6	4.7	0.45	0.813	--

SOURCE NOTES: U.S. Congress, House, Committee on Government Operations, *Federal Real and Personal Property Inventory Report*, Committee Print, (Washington, D.C.: Government Printing Office, viennial.

Column (1) includes Maintenance, R&D, Test, Training, and Waterfront Facilities only.

Comment on Table 27:

The results of the table derive from adjusting the combined Military and Civilian levels of Table 28 with the Equivalent Manning Level (EML) of Table 29. The ratio of required manpower to actual manpower was not available for officer or civilian personnel. It is therefore assumed that the EML for Navy enlisted personnel is representative of these other categories.

TABLE 27 -- Estimated Manpower Requirements for Weapon Hardware Held by U.S. Navy (Thousands of Persons)

Fiscal Year	Estimated Manpower (M_t)	Fiscal Year	Estimated Manpower (M_t)
1955	983	1965	979
6	965	6	1,067
7	964	7	1,113
8	976	8	1,086
9	954	9	1,078
1960	936	1970	967
1	935	1	886
2	976	2	852
3	971	3	840
4	991	4	825

NOTE: Estimated manpower is column (4) of Table 28 divided by column (3) of Table 29.

TABLE 28 -- Navy Manpower Categories for Selected Years

(Thousands of Persons, End of Fiscal Year)

Fiscal Year	Active Navy Military (1)	Navy & Marine Corps Civilians (2)	Estimated Navy Civilians (3)	Navy Civilian & Military (4)=(1)+(3)
1952	--	481	347	--
1955	661	--	(322)	(983)
6	(660)	--	(304)	(965)
7	(655)	--	(299)	(954)
8	641	--	(295)	(931)
9	626	--	(280)	(906)
1960	618	348	271	889
1	627	(348)	271	(898)
2	666	348	271	937
3	665	344	268	933
4	668	333	259	927
1965	672	330	257	929
6	(745)	354	262	1,007
7	751	403	290	1,041
8	765	416	295	1,060
9	777	424	301	1,078
1970	692	376	275	967
1	623	350	263	886
2	588	342	256	844
3	564	322	(242)	806
4	551	326	(245)	796

SOURCES: Department of the Navy, Office of the Comptroller "Budget and Forces Summary" NAVSO P-3502 (Washington, D.C.: May 1974). Office of the Assistant Secreatry of Defense (Comptroller) "Five Year Defense Program Historical Summary for Fiscal Years, 1962-1972," Memorandum dated June 7, 1973, unclassified portions, table 2 (Computer Printout). Roger N. Little (ed.), Handbook of Military Institutions (Beverly Hills, CA.: Sage Publications, 1971) Appendix. Department of Defense, Secretary of Defense James R. Schlesinger Annual Defense Department Report 1975 (Washington, D.C.: Government Printing Office, March 1974) p. 172.

NOTE: Column (3) is product of column (2) and elements of Table 31 except 1952 entry is based on assumed equivalence (in Navy to total Navy and Marine Corps ratio) of 1952 and 1967, which are both peak war years.

Comment on Table 29:

The Equivalent Manning Level (EML) for enlisted personnel was derived through the following rationale. The end intent is to deduce the hardware/manpower ratio for Navy systems. This ratio is to be compared with the ratio of manpower costs to hardware costs in order to determine Defense efficiency. Given weapon levels through time, manpower levels required to man those weapons must be obtained. However, available manpower data is <u>actual</u> manpower levels rather than <u>required</u> levels. Furthermore actual levels are often distorted by non-economic effects such as war-to-peace transition periods. To decide whether Defense procurement has responded to factor price changes, a conversion from actual manning levels to the levels required by the systems procured is needed.

To do this, enlisted personnel grades were grouped into three sub-groups: E-1 personnel, E-w and E-3 personnel, and E-4 through E-9 personnel. E-1 personnel are essentially recruits, and do not man systems. E-2 and E-3 personnel are assumed unskilled in that they are normally not trained to repair equipments, though they can operate systems given supervision. E-4 through E-9 personnel are skilled, and represent the bulk of trained repairmen, supervisors, etc. While these classifications are oversimplified, they are suitable for present purposes.

Since E-1's are not involved in system operation, their manning level is temporarily disregarded. Suppose now that the E-2,3 category is manned at 120%, while the E-4,9 category is at 80%. If all manpower categories are combined, a manning level of about 100% results. If an equivalent manning level of 1.0 is therefore assumed, and the actual manpower level divided by EML is used to estimate the required level, then it is felt that this will be an erroneous indication of the manpower required. The overage in unskilled personnel does not compensate for the shortage in skilled personnel, for the unskilled cannot perform the work of the skilled.

To emphasize the point, consider the opposite case. If the unskilled were manned at 80%, and the skilled at 120%, then it seems intuitive to conclude that the overall manning level is more than 100% -- for the skilled can do the work required of the unskilled (since the only way to become an E-4 is to have been an E-3), and usually much more, since they can repair equipment.

There are unlimited ways to adjust for the manpower overages and shortages of Table 30 in order to arrive at an EML. The method chosen is the following which is arbitrary but intuitively consistent with the data and sensitivity of the research. If the E-2,3 category is manned in excess of 100% (which it is for all years considered) it is assigned

a value of 1.0. This value is then averaged with the manning level for the E-r,9 category, the weighting being equal since the two groups are of approximately the same size. The average figure is then the EML. This is used to convert actual manning levels into the Manpower Requirement levels of Table 27.

TABLE 29 -- Estimated Equivalent Manning Level (EML) for U.S. Navy in Selected Years

Fiscal Year	Manning Level E-2, E-3 (1)	Manning Level E-4, E-9 (2)	EML (3)
1955	--	--	(1.0)
1956	--	--	(1.00)
1957	--	--	(0.99)
1958	--	--	(0.96)
1959	1.0	0.90	0.95
1960	1.0	0.90	0.95
1961	1.0	0.92	0.96
1962	1.0	0.92	0.96
1963	1.0	0.92	0.96
1964	1.0	0.87	0.94
1965	1.0	0.92	0.95
1966	1.0	0.89	0.94
1967	1.0	0.87	0.94
1968	1.0	0.95	0.98
1969	1.0	1.00	1.00
1970	1.0	1.00	1.00
1971	1.0	0.99	1.00
1972	1.0	0.98	0.99
1973	1.0	0.91	0.96
1974	1.0	0.91	0.96

NOTES: Column (1) is 1.0 throughout because average manning level for E-2, E-3 exceeds 100% each year (see Table 30). Column (2) is weighted average of manning levels for E-4 through E-9 from Table 30. EML is average of columns (1) and (2). All figures rounded to digits shown. See text for further discussion.

TABLE 30 -- U.S. Navy Enlisted Manpower Required and Percentage of Required on Board by Grade and Year (Manpower in Thousands of Men)

Year (June)	Pay Grade Required Manpower/Percent on Board)							
	E-1	E-2	E-3	E-4	E-5	E-6	E-7/9	Total
	Req/%	Req/%	Req/%	Req/%	Req/%	Req/%	Req/%	Req/%
1959	022/095	064/124	132/118	110/092	092/085	078/086	048/094	548/101
1960	021/109	061/128	129/115	112/090	092/088	074/090	041/094	537/101
1961	021/097	061/141	136/103	115/093	094/093	075/086	048/098	549/100
1962	021/108	062/167	141/094	120/094	101/093	081/084	049/099	576/101
1963	021/100	064/143	141/101	121/095	102/091	082/085	050/100	582/100
1964	021/100	065/147	143/106	125/089	104/085	083/082	050/096	592/099
1965	021/111	071/119	144/108	124/094	105/088	082/084	051/091	597/098
1966	027/099	070/165	145/114	138/094	116/084	088/086	053/092	638/103
1967	026/090	074/108	155/132	143/091	121/083	091/084	054/091	664/100
1968	025/103	077/109	163/103	144/101	123/094	093/088	055/095	681/099
1969	025/117	075/131	164/088	144/106	121/100	090/094	055/102	674/102
1970	022/083	065/117	138/104	125/106	110/092	083/098	052/103	595/102
1971	017/075	054/099	123/109	116/102	101/093	077/100	050/102	539/101
1972	020/166	040/125	110/098	107/098	096/095	075/101	050/098	498/103
1973	012/265	039/207	115/065	109/090	097/088	077/094	050/096	498/098
1974	018/192	035/206	107/077	100/093	092/087	074/090	049/094	475/100

SOURCE: Department of the Navy, Bureau of Naval Personnel and Headquarters, U.S. Marine Corps "Navy and Marine Corps Personnel Statistics," NAVPERS 15658, Monthly Reports, June issues.

TABLE 31 -- Ratio of Navy Manpower to Total Navy and Marine Corps Manpower Based on Actual Manpower Levels Maintained for Selected Years

Year(s)	Ratio	Year	Ratio
1957-61	(0.78)	1968	0.71
1962	0.78	1969	0.71
1963	0.78	1970	0.73
1964	0.78	1971	0.75
1965	0.78	1972	0.75
1966	0.74	1973	(0.75)
1967	0.72	1974	0.74

SOURCE: Assistant Secretary of Defense (Comptroller) "Five Year Defense Program, Historical Summary for Fiscal Years 1962-1972," Memorandum dated June 7, 1973, unclassified portions, Table 2 (Computer Printout).

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